Chapter 1

Introduction

1.1 An Introduction to Active Galaxies

Within the multitude of galaxies that are observed in the universe, some contain extraordinarily high luminosity nuclei. These sources are often brighter than the rest of their host galaxy and appear to originate from a small, but highly active central area. With the intention of providing an explanation for the properties of these objects several theoretical models have been proposed. The most successful and widely accepted of these models employs accretion of material onto a supermassive black hole to provide the energy for the most luminous of these sources. The resultant release of large quantities of gravitational potential energy as matter falls onto the black hole results in a highly compact luminous central core, which is often referred to as an Active Galactic Nucleus (AGN). In lower luminosity active galaxies it is often unnecessary to employ such models since the observed luminosity can be explained by a period of intense star-formation. In starburst and many luminous infrared galaxies these extremely high rates of star-formation are expected to provide the dominant energy source. These explanations are not mutually exclusive with several objects best explained by a power source that is a combination of both starburst and AGN activity. Without question both starburst dominated galaxies and galaxies harboring an AGN will require large volumes of material, in particular gas and dust, to fuel their activity. The source of this material, whether from within the host galaxy or stripped from a close by neighbour, and the methods by which it is transported into the central active region are fundamental to understanding of how these objects are triggered, fuelled and interact with their environment.

This chapter will initially outline some of the characteristics of these sources as well as the physical processes that may lead to their formation and fuelling. This is followed by an outline of the observational techniques used and motivations for the work presented in this thesis.

1.2 Characteristics & Classification of Active Galaxies

All active galaxies have one thing in common; the huge amounts of energy that they emit from within a small central region. Besides this, active galaxies exhibit diverse observational characteristics. Active galaxies are been classified in terms of their physical appearance and the radiation that they emit.

1.2.1 Active Galactic Nuclei

Those active galaxies that contain an AGN as their dominant power source can be categories in terms of their luminosity and appearance. AGN fall into two broad families; those with low flux density at radio wavelengths, compared to their optical luminosities and those with high radio flux densities in comparison to their optical luminosities (Miller et al. 1993). The split between these two families is apparent when the radio luminosities of a sample of AGN are plotted against their optical line (e.g. [OIII] which is regarded as one of the best orientation indicators of the luminosity AGN (Miller et al. 1992; Jackson & Browne 1991a & 1991b)) luminosities (Xu et al. 1999). Morphologically radio-loud objects are almost always associated large-scale radio emission, whereas radio-quiet sources have little radio emitting ejecta. Radio-quiet sources are normally associated with spiral or SO galaxies, while radio-loud objects are generally found in early-type galaxies (Xu et al. 1999). The majority of galaxies that harbor an AGN fall into the radio-quiet category.

These two families, radio-quiet and radio-loud, can be further sub-divided into individual classes of objects. These divisions have historically been made by virtue of their observed optical spectrum. On this basis AGN are classed as members of one of three basic types.

- *Type-0*: Optical spectrum contains weak or no emission lines relative to a very strong continuum emission. There are no radio-quiet objects that appear to fit into this classification.
- *Type-1*: Optical spectrum contains both permitted broad ($\Delta V \sim 10\,000\,\mathrm{km\,s^{-1}}$) and forbidden narrow emission lines.
- *Type-2*: Optical spectrum only contains narrow (both permitted and forbidden) emission lines ($\Delta V < 1000\,\mathrm{km\,s^{-1}}$). No broad emission lines are observed.

Within these three types there are several magnitudes of variation in the observed luminosities of these objects and a multitude of physical sizes and structures. These other physical characteristics are also used to further sub-divide active galaxies into classes of objects, such as *radio galaxies, Seyfert galaxies* and *quasars*.

Radio-Quiet AGN

Radio-quiet AGN dominate the numbers of observed AGN sources within the local universe with around 90% of AGN falling into this category. Amongst these sources, the most common in the local universe are Seyfert galaxies. The majority of Seyfert nuclei are associated with spiral host galaxies and are thought to reside in $\sim$2% of all spiral galaxies. Seyferts can be classified as either type-1 or type-2 from their optical spectra (Weedman 1970). Type-1 Seyferts displaying broad permitted lines, such as the Balmer lines, in conjunction with forbidden emission lines. The widths of these permitted lines can be attributed to Doppler broadening by gas with high bulk motions, hence are thought to originate in areas close to the AGN. As well as type-1, some Seyfert nuclei are observed to only display narrow emission lines. These fall into the type-2 category with line widths that infer only relatively small gas bulk motions of a few hundred to a thousand $\mathrm{km\,s^{-1}}$. Although Seyfert nuclei are classified as radio-quiet, many produce radio emission on linear scales of a few 10s to hundreds of parsecs, and are easily studied at radio wavelengths. The most luminous Seyfert nuclei produce radio flux densities that are comparable to low luminosity, radio-loud objects (Thean et al. 2001; Kukula et al. 1995).

At the lowest end of the AGN luminosity scale there exist a class of sources which have some similarities to Seyfert-2 galaxies. These low-ionisation nuclear emission region galaxies (LINERs) are the weakest of the AGN classes and resemble normal galaxies in many ways, but do show optical emission lines in their nuclear regions. Spectroscopically LINERs are classified as type-2 sources. The broad lines emitted from LINERs appear less broad ($>$10 000 $\mathrm{km\,s^{-1}}$) than the equivalent broad lines from Seyfert-2 galaxies (Heckman 1980). Additionally LINERs display strong low ionisation lines compared to Seyfert-2 galaxies (Heckman 1980). Observations of LINER sources have lead to the suggestion that many galaxies that have been classified as 'normal' may have some degree of nuclear activity. This intriguing possibility may even imply that all galaxies pass through a phase of activity in their lifetimes. The observed luminosities of LINERs overlap with those of starburst dominated galaxies possibly implying that mechanisms other than AGN activity, such as shock excitation or photoionisation by stars, maybe responsible for their observed emissions (e.g. Filippenko 1996). Regardless of the true source of the activity observed in these objects they form an intriguing class of active galaxies.

Quasi-stellar-objects (QSOs) and quasi-stellar-radio-sources (quasars) encompass a range of compact luminous sources. Of these, some are classified as radio-loud, such as the core and lobe-dominated quasars (discussed latter), whereas a significant number are radio-quiet. Similar to Seyfert nuclei, radio-quiet quasars can be classified as type-1 or type-2 objects by virtue of the optical emission lines. In fact, the only significant difference between Seyfert nuclei and the radio-quiet quasars are their luminosities. If an AGN with Seyfert-like characteristics is observed to be so luminous as to make it difficult to separate from the host galaxy it is referred to as a quasar (i.e. appears star-like).

Radio-Loud AGN

There is a wide spectrum of physical size associated with the radio emission from radio-loud AGN, ranging from compact nuclear emission on parsec scales to radio jets and lobes that often stretch well beyond the optical extent of their host galaxies.

Radio galaxies display emission over the largest angular sizes of all AGN and are the dominant astronomical population at wavelengths greater than 1 cm. The radio emission from these sources usually consist a compact core region from which collimated jets emerge. The jets from radio galaxies eventually interact with the ambient galactic or intergalactic medium to form lobe-like structures (Begelman, Blandford & Rees 1994). As with most radio-loud AGN, radio galaxies are normally associated with large elliptical host galaxies. Radio galaxies have been further classified due to their physical appearance into the Fanaroff-Riley classes, FR1 and FR2 (Fanaroff & Riley 1974). FR1 radio galaxies are generally low luminosity objects with their radio brightness dominated by their core emission. The majority of FR1 radio galaxies have two-sided radio jets and lobes which diminish in brightness as they get further from the central core. Spectroscopically FR1 galaxies contain only narrow optical emission lines and hence are grouped as type-2 AGN. FR2 radio galaxies are usually larger and more luminous than their FR1 counterparts. FR2 radio galaxies also contain jets and core components but are edge-brightened with large, high luminosity radio lobes. The radio emission from the lobes of FR2 radio galaxies is considerably brighter than the emission from their core and jet. Optical spectroscopy of FR2 galaxies characterises some as type-1 whereas others only show narrow lines. Hence FR2s can be further divided into two sub-classes which are referred to as broad line radio galaxies (BLRGs) and narrow line radio galaxies (NLRGs) respectively.

Amongst the radio-loud AGN there are also compact quasars. The spectra of quasars show highly redshifted emission lines implying that they are at large distances. Quasars are also extremely luminous with total energy outputs that range up to 10^{41} W. At X-ray wavelengths quasars can have luminosities that vary on time-scales of between minutes and hours confirming their compact nature (e.g. Tennant et al. 1981). Many quasars have one-sided radio jets which dominate their radio emission (Hough et al. 2002). Optically these lobe-dominated quasars appears to have similar spectra to BLRGs (type-1) whereas quasars that are dominated by core emission have a type-0 spectra.

Core-dominated quasars also have lower radio luminosity counterparts, blazars. The blazars fall into two categories, the BL Lacs and the Optically Violent Variable quasars (OVVs). All blazars display highly variable radio and X-ray emission on time-scales of minutes to days (Maraschi et al. 1989) and thus are physically compact. Blazars have strongly polarised optical continuum with no emission lines (type-0) and hence have many similarities with the more luminous, core-dominated quasars.

Summary

The previous two parts of this section have given an overview of some of the important classifications of AGN dominated active galaxies and discussed some of their observed properties. It is apparent that there is a wide range of sizes, structures and luminosities observed in AGN, but it is also relatively clear that there are many similarities within the properties of each group, as well as between certain classes of sources. For example, the more powerful Seyfert-1 galaxies show many of the same physical phenomena as low luminosity lobe-dominate quasars. Also weak FR1 radio galaxies share many physical properties with the more luminous Seyfert-2 galaxies, including narrow emission line spectra and two-sided radio jet emission that generally decreases in luminosity as a function of distance from the core. Observationally it is clear that many these sources are axisymmetric (e.g. emit two-sided radio jets) and that their observed structure may differ depending on their orientation with respect to the observer. For example, FR1 radio galaxies are thought to be observed with their jets aligned to the sky plane but if they were observed along the axis of their jets their characteristics may correspond to blazar/BL Lac objects.

An extension to these ideas has lead towards the development of theoretical schemes and models which aim to explain the similarities and differences observed between the different groups of AGN. These models aim to explain the diverse properties of AGN in terms of the underlying physical processes involved and their orientation with respect to the observer.

1.2.2 Orientation Dependent Unification Models

The first orientation dependent explanation for the observed characteristics of different classes of AGN was proposed by Roberto Antonucci in the early to mid-1980s (Antonucci 1982, 1984 and Antonucci & Miller 1985). In particular, Antonucci & Miller (1985) observed hidden, polarised, broad Balmer line emission from the Seyfert-2 nucleus NGC 1068. These broad lines had nearly identical polarisation as the nuclear component. It was therefore concluded that this non-stellar component was scattered emission that originated close to the nuclear region. Their conclusion was that the continuum and broad line emission regions of this source were located within an optically obscured area, with the optical obscuration most likely resulting from a geometrically and optically thick disc of material. This idea has developed into a *standard model* to explain the observed characteristics of AGN. Fundamentally this model is based around the idea that a *torus* of gas and dust obscures the nuclear emission line regions producing different observed characteristics when viewed from different orientations.

The current standard model for AGN is schematically represented in Fig. 1.1 and has been reviewed by many people (e.g. Lawrence 1987; Antonucci 1993; Ward 1996). The basis for this model follows the provisos that the primary energy source for all AGN is accretion onto a supermassive object (a black hole) and that this region is surrounded by an optically and geometrically thick region of obscuring material.

It is thought that the observed broad and narrow emission lines are emitted from ionised gas that exists in different regions surrounding the AGN. The broad line region (BLR), responsible for the broad permitted optical transition lines, and none of the forbidden lines, consists of an area of ionised gas with a high density ($n_e > 10^8\,\mathrm{cm}^{-3}$). Broad lines are observed to have widths of order $\sim$10 000 km s^{-1} indicating that this gas is hot and fast moving, with the gas motions, probably

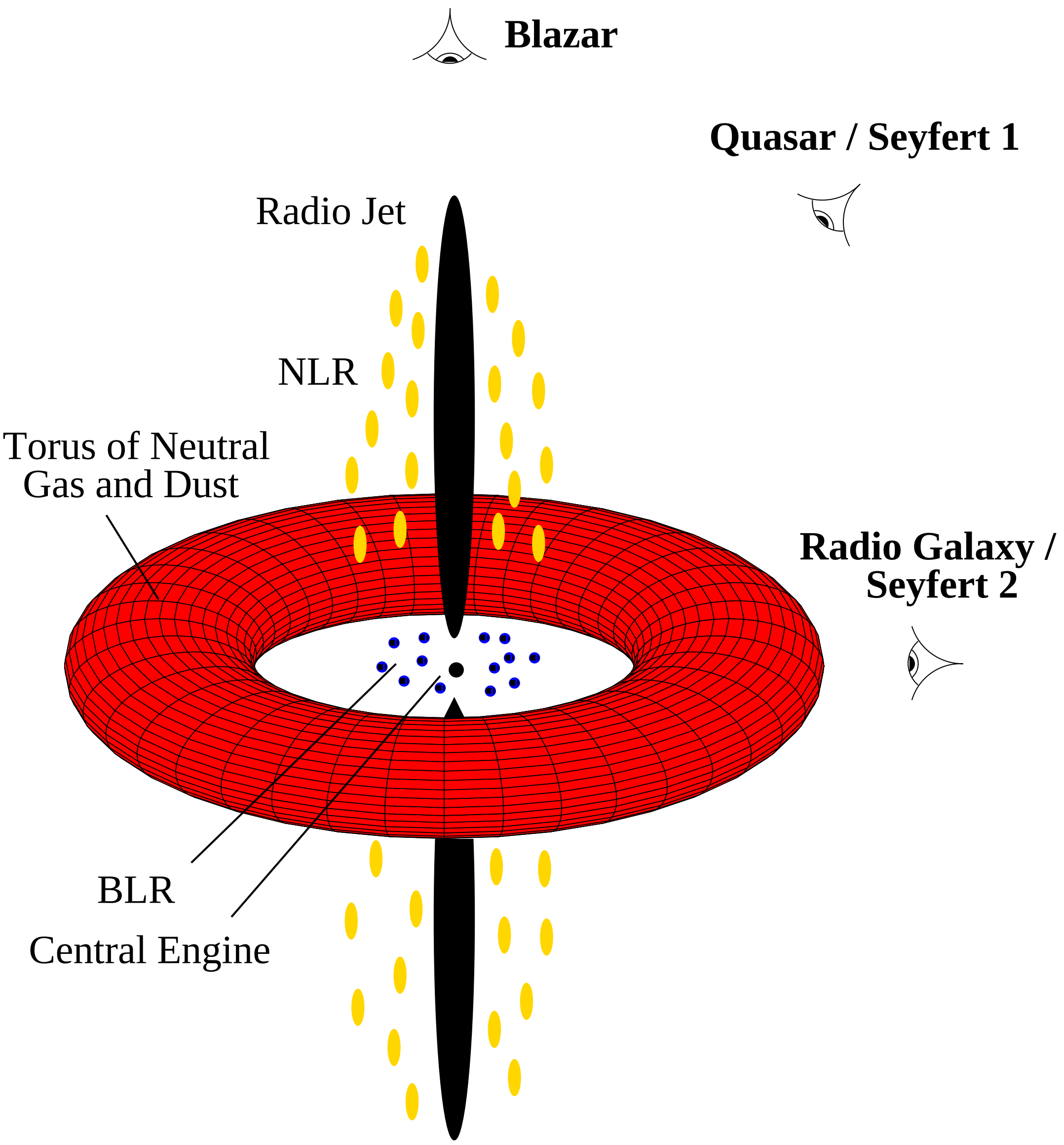

Figure 1.1: A schematic representation of the orientation dependent standard model of AGN. This model explains the observed properties of the AGN determined by its power and the orientation of a circumnuclear torus of neutral gas and dust with respect to the line of sight of the observer. (Figure taken from Cole 1999.)

driven by a combination of gravitational rotation, turbulence and radiation pressure. In order for the emitted radiation to escape this high density region it is also required that the BLR has a small filling factor implying that it is most likely composed of small dense clouds. It is thought that this region extends up to $\sim$1 pc from the AGN.

From observations of only narrow lines in type-2 AGN it is clear that the region from which narrow emission lines originate (narrow line region, NLR) is not coincident with the BLR. The NLR is characterised by the observation of narrow emission lines including forbidden lines, such as [OIII], implying that the ionised gas exists in less dense regions ($n_e \sim 10^4\,\mathrm{cm}^{-3}$) than found in the BLR. The observed line widths of the NLR are only a few hundred $\mathrm{km\,s}^{-1}$ suggesting considerably less turbulent gas motions than the BLR. It is thought that this region is situated between $\sim$10 and 100 pc from the AGN.

It has also been found in observations, particularly of Seyfert-2 galaxies, that the NLR can extend out to as far as $\sim$20 kpc from the nuclear region (Unger et al. 1987). This extended narrow line region, ENLR, is normally observed to have a biconical distribution along the same axis as the collimated radio ejection. It is considered that the biconical distribution is indicative of gas being photoionised by UV radiation or affected by the jet emission from a central engine that is partially obscured (Quillen et al. 1999).

The energy source or central engine of all active galactic nuclei is general considered to be powered by accretion onto supermassive black hole. This central engine is the source of the highly collimated, relativistic, radio plasmon ejection and large scale radio structures, such as radio lobes, that are observed in some sources. This model requires that a central black-body of mass $10^6 \rightarrow 10^9\mathrm{M}_\odot$ accrete material at a rate of between 10^{-2} and $10^2\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ depending upon the power of the AGN and the efficiency of the energy conversion of the process. The physical area in which this is considered to occur is small (can vary on time-scales of minutes) and is unresolved by present observations. Alternative energy sources have been proposed for this central source, such as compact regions of extreme star-formation (e.g. Terlevich et al. (1992)). It is conceivable that these starburst models have some validity, especially in explaining lower luminosity classes of AGN (e.g. LINERS). However starburst models have considerable difficulties in recreating the power emitted by higher luminosity AGN, such as quasars and powerful radio galaxies. It should be noted that there are only fine distinctions, if any, between some of the observed characteristics of low luminosity AGN and starburst dominated active galaxies (see section 1.2.4). Considering this it is logical to assume that starburst emission does have some role in powering at least some AGN.

Probably the most important component in this standard view of AGN is the so called thick obscuration required for unified schemes or 'dusty' torus. The composition of the torus or disc is most likely to be a combination of atomic gas (predominately neutral hydrogen), dust and a multitude of molecular gas species. This torus is required to obscure certain regions around the AGN from the observer when viewed along certain lines of sight. Thus implying a geometrical size that is large enough to obscure the BLR (i.e. greater than a few parsecs) but small enough not to obscure the NLR (i.e. smaller than a few hundred parsecs). The opening angles of this obscuring torus are expected to vary from source to source but are required to be large enough to allow ionising radiation to reach the NLR and ENLR. The conical morphology of the narrow line emitting regions in some galaxies have allowed estimates of the torus opening angle to be made, such as in NGC 5252 where Tadhunter & Tsvetanov (1989) have implied opening angle of $\sim 40°$. Also spectropolarimetry observations of scattered broad lines in some type-2 sources, for example the Circinus galaxy (Alexander et al. 2000), have inferred similar opening angles for the obscuring torus. Although the torus is an integral part of the standard model it is still relatively ill defined by observation.

1.2.3 Starbursts & Luminous Infrared Galaxies

Starburst galaxies can be considered as active galaxies because they too produce prodigious quantities of emission but due to the origins of their power source, extreme bursts of star-formation, are different to the AGN sources outlined in the previous few pages. The star-formation rates observed in these galaxies are extreme and not sustainable for the whole duration of the galaxies lifetime. Typically the starburst phase will last $\sim 10^7$ to 10^8 years (Larson & Tinsley 1978) compared to the average lifetime of a galaxy of $\sim 10^{10}$ years. The central regions ($<$few hundred parsecs) of starburst galaxies are heavily obscured by gas and dust in the optical, with only infrared, radio and X-ray observations able to penetrate this interior. This large dust content and rapid star-formation is responsible for the high infrared emission that characterises these sources. The dust surrounding these starbursts regions will absorb the UV radiation emitted from hot young stars and re-radiate this energy at infrared wavelengths (Rieke et al. 1980). Extended areas of radio emission are also observed from starburst galaxies (e.g. Condon et al. 1991). This non-thermal radio emission originates from relativistic particles produced and accelerated by supernova (SNe). There is a strong correlation between the observed infrared and radio flux densities of starburst galaxies which is thought to trace the star-formation rates in these galaxies (e.g. Cram 1998; Yun et al. 2001).

Bright infrared (IR) galaxies are more numerous than optically selected QSOs, Seyfert and starburst galaxies of comparable bolometric luminosities ($L_{\rm bol} > 10^{11}\,L_\odot$) and form the dominant population of extra-galactic sources in the local universe ($z \lesssim 0.3$) (Sanders & Mirabel 1996; Telesco 1988). The most luminous (in the infrared) of these sources are often referred to as the luminous infrared galaxies (LIRGs: $L_{\rm fir} \gtrsim 10^{11} L_\odot$) and the ultra-luminous infrared galaxies (ULIRGs: $L_{\rm fir} \gtrsim 10^{12} L_\odot$). The origin of the huge IR luminosities from these galaxies is considered to be the dust that surrounds their central regions. This dust absorbs UV emission from either an AGN (Shier et al. 1996) or hot, young stars in a starburst (Crawford et al. 1996) and then re-radiates this energy at IR wavelengths. It is still uncertain whether AGN or star-formation provide the dominant power source in luminous infrared galaxies, with many dusty-enshrouded AGN and starburst galaxies classified as LIRGs or ULIRGs on the basis of their IR luminosities. In fact, observations of the archetypical ULIRG Arp 220 (Smith et al. 1998a) show this source contains numerous radio supernovae (RSNe) implying the presence of a starburst, whereas another prototypical LIRGs NGC 6240 (see chapter 5) shows evidence for an AGN.

Observations have shown that almost all luminous infrared galaxies show evidence for strong tidal interactions with nearby companion galaxies or are involved in mergers (Borne et al. 2000). Many starburst galaxies and galaxies that harbor classical AGN have also been observed to have either recent or ongoing galaxy-galaxy interactions (Dahari 1985; Heckman et al. 1986; Lonsdale et al. 1984). These observations have lead to the suggestion that activity in galaxies may be some how induced by powerful galaxy-galaxy interactions involving gas-rich progenitors (Solomon et al. 1997; Genzel et al. 1998). This possibility will be discussed in more detail later in this chapter.

1.2.4 Starburst–AGN Connections

There are undeniable differences in the properties that are observed in starburst powered galaxies and AGN powered galaxies. However, there are an increasing number of sources are observed to show both starburst and AGN characteristics, for example, the Seyfert galaxies NGC 1068 & NGC 7469 (Gallimore et al. 1996; Colina et al. 2001a; chapter 4 of this thesis). In the population of LIRGs it is thought that the majority (70% →80%) are dominated by starburst emission (Genzel et al. 1998). This assertion is supported by high resolution continuum radio observations of sources that reveal resolved radio continuum distributions which are consistent with radio emission from a starburst (e.g. Arp 220 Smith et al. (1998a), Mrk 273 Carilli & Taylor (2000) and III Zw 35 Pihlström et al. (2001)). However, it has also been shown that there is a strong tendency for the incidence of AGN within ULIRGs to increase as a function of the IR luminosity (Genzel et al. 1998; Veilleux et al. 1995).

To trigger either AGN or starburst activity requires large volumes of material to be fed into the central part of the galaxy. The main types of phenomena that can successfully supply this fuel into the nuclear region are tidally disturbing interactions between galaxies and the formation of bars (see section 1.3). With the similarity between fuel required and the likely mechanisms by which it is transported into the centres of active galaxies it is not surprising that there is a degree of synergy between these two forms of activity. It was suggested by Hummel et al. (1990) that, although it is straightforward to transport gas to within 1 kpc of the nuclear region and induce enhanced star-formation, it is far more difficult to continue this fuelling to the smaller scales required to trigger, and subsequently fuel, AGN activity. Their conclusion was that, although interactions and bars may play a role in the transportation of material from the outer parts of the galaxy to intermediate scale distances of ~1 kpc from the centre, the transport of gas into the nuclear region is mainly dependent upon the distribution of mass within the galaxy. Thus the formation and fuelling of AGN activity is harder to induce than starburst activity.

The similarities in the way both starburst and AGN activity are fuelled and induced does suggest a strong connection between AGN and starburst galaxies but there are many unanswered questions as to what this connection is and what it actually implies. Is this connection merely an indication of the the similarities in the fuelling methods between these two classes or is it a more fundamental? Is there an evolutionary sequence (e.g. Taniguchi 1999) during which the starburst/ULIRG phase will eventually evolve into an AGN phase? If this connection is a representation of some evolution of galaxy type, those sources that show evidence of both processes may provide an important snapshot in this evolutionary track.

1.3 Triggering & Fuelling of Activity in Galaxies

For starburst and AGN activity to be triggered and then sustained within the central regions of galaxies, fuel in the form of gas and dust is needed to be fed into this region at a rate of approximately few $M_{\odot}\,\mathrm{year}^{-1}$. It is also clear from observations that activity (e.g. starburst activity) require an unsustainable volume of fuel, hence must be a transient phase in the life of some galaxies, and therefore must have an initial trigger. It is still unknown exactly how activity is triggered. It is also not certain what physical mechanisms are involved in the transportation of material into the inner few parsecs of a galaxy. One of the key questions is, what processes cause the material/fuel to lose its angular momentum and hence be allowed to fall inwards. It is thought that once material is within the last few parsecs of the central engine that viscous forces within an accretion disc will provide an adequate means in which the angular momentum can be dissipated and enable mass to fall onto the central engine (Rees et al. 1982) but this still requires the material to be fed into this region.

Figure 1.2 (from Shlosman, Begelman & Frank 1990) describes series of means by which fuel can be provided for activity in galaxies. Although, this scheme provides a somewhat idealised representation of the processes involved, it does serve to illustrate some of the complexity involved in any effort to understand fuelling mechanisms. The next two sections will discuss two of the physical processes involved which are often cited as the most important factors in the triggering and fuelling of activity; galaxy-galaxy interactions and bar potentials.

Interactions and Mergers

There have been numerous investigations of incidence of nuclear activity within interacting galaxies (e.g. Kennicutt & Keel 1984; Keel et al. 1985; Dahari 1985; Bushouse 1986 &1987; Telesco et al. 1988; Bergvall & Johansson 1995). These have shown some correlation between galaxies involved in interactions and/or mergers and activity in these sources. In particular, Seyfert galaxies have been observed to show a probable excess of companion galaxies (e.g. Dahari 1985). Although such an excess is still not fully confirmed there is a trend (at close to the 95% significance level) that Seyfert-2 galaxies do have more companions than normal disc galaxies (de Robertis et al. 1998). It is however important to note that, although there is a likely trend for a higher rate of interactions involving Seyfert hosts than normal galaxies, only ∼10% of all Seyfert galaxies have companions (e.g. Rafanelli et al. 1995). It has also been found that activity amongst Seyfert galaxies that do have companions displays no preference for a particular kind of interaction (e.g. prograde, polar or retrograde) even though the most efficient fuelling should occur in prograde interactions (Keel 1996). This would imply that, at least in the case of Seyfert activity, galaxy interactions play only a minor role in triggering nuclear activity.

Observation of starburst and infrared galaxies have found that a large fraction are involved in some form of interaction or have highly disturbed morphologies (Soifer et al. 1984). These observations have shown that galaxies involved in extreme mergers appear to preferentially produce periods of strong starburst activity, such as is observed in Arp 220 and Mrk 273, with such strong interaction playing an important role in the triggering of activity (Larson & Tinsley 1978; Barnes &

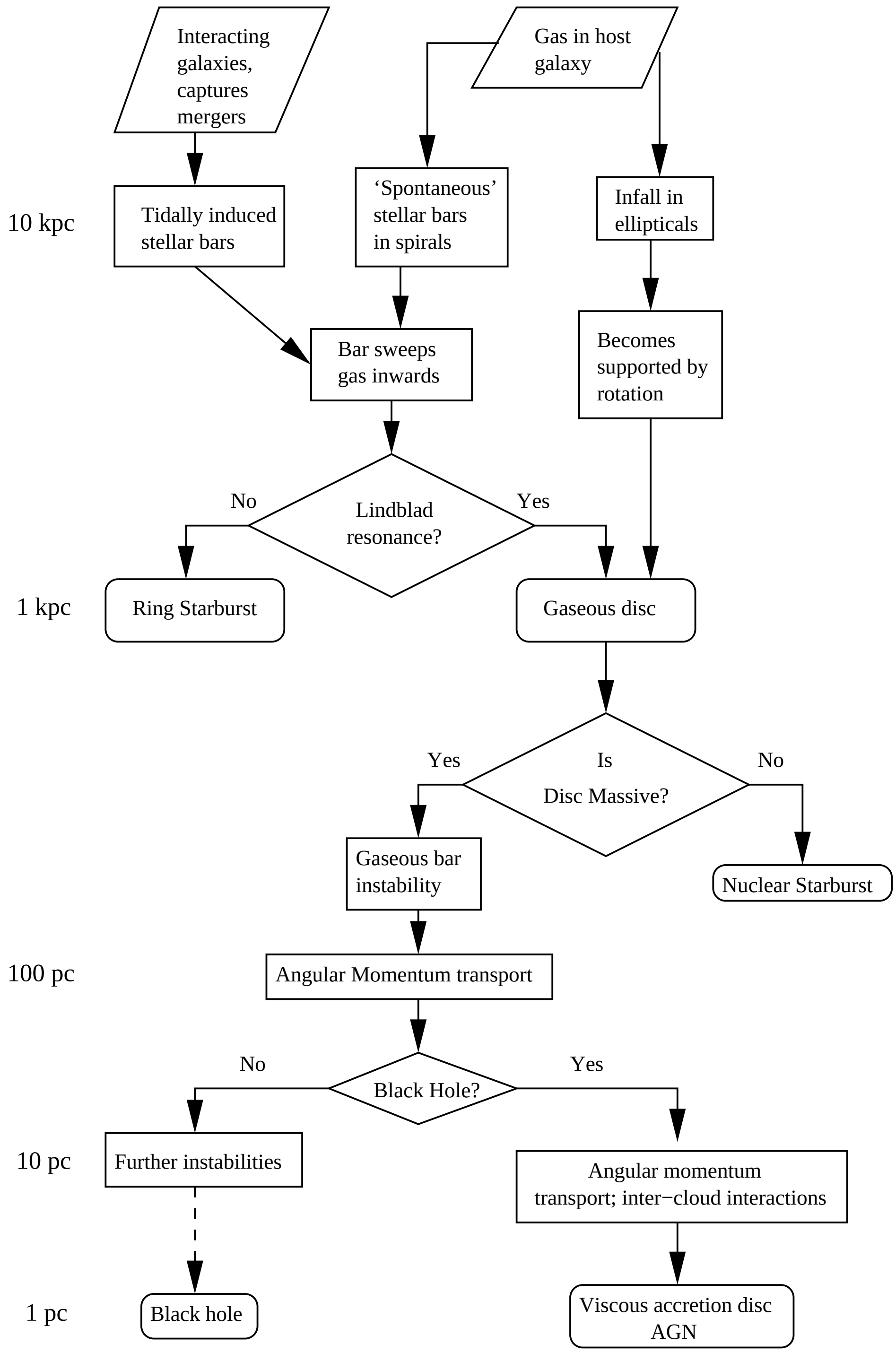

Figure 1.2: An schematic representation of a unified model for fuelling activity in galaxies (From Shlosman, Begelman & Frank 1990). The different pathways represent methods by which material may pass towards either an supermassive black hole or a region of star-formation and hence fuel AGN and/or a starburst activity.

Hernquist 1996). Interactions will cause asymmetries and perturbations in the mass distribution of the galaxy and result in the formation of instabilities that feed material into the centre of the galaxy. Interactions and mergers between gas rich galaxies will also result in an increased volume of fuelling material available, via tidal stripping processes and the subsequent cannibalisation of gas and dust by the dominant galaxy in the interaction.

In higher redshift AGN sources, such as quasars and radio galaxies, signatures of interaction and disturbed morphologies are also observed (Turner 1991). Radio-loud AGN are known to reside within giant elliptical galaxies which typically contain a smaller fraction of gas than the spiral hosts of Seyferts, thus increasing the need for additional fuel to be acquired from outside the host galaxy, with cannibalisation of gas from companions being the most likely explanation.

Some models have suggested that the role of mergers may not only be significant in the initial triggering of activity and subsequent fuelling, but might also fit into an evolutionary path for active galaxies (see Fig. 1.3 from Taniguchi 1999). It is apparent that the starburst galaxies and, in particular, the ULIRGs in the local universe display a high incidence of extreme mergers events. Many high powered radio-loud AGN, which are more common in the higher redshift universe (z$\sim$1–2), also show evidence for some level of distortion indicative of past interactions. These radio-loud AGN also reside in giant elliptical galaxies that are thought to be formed as the result of past galactic mergers (Barnes 1989; Hernquist & Barnes 1991; Kormendy & Sanders 1992). So it can be argued that the present ULIRG phase observed in some local galaxies is merely one step towards the formation of the higher powered AGN that are seen at higher redshift. This of course maybe merely a result of the misidentification of the power source of *some* ULIRGs since it is certain that some are powered by highly obscured quasars (Colina et al. 2001b). These hidden quasars may only expose themselves later in their life as their obscuring shroud is either blown away by their radiation

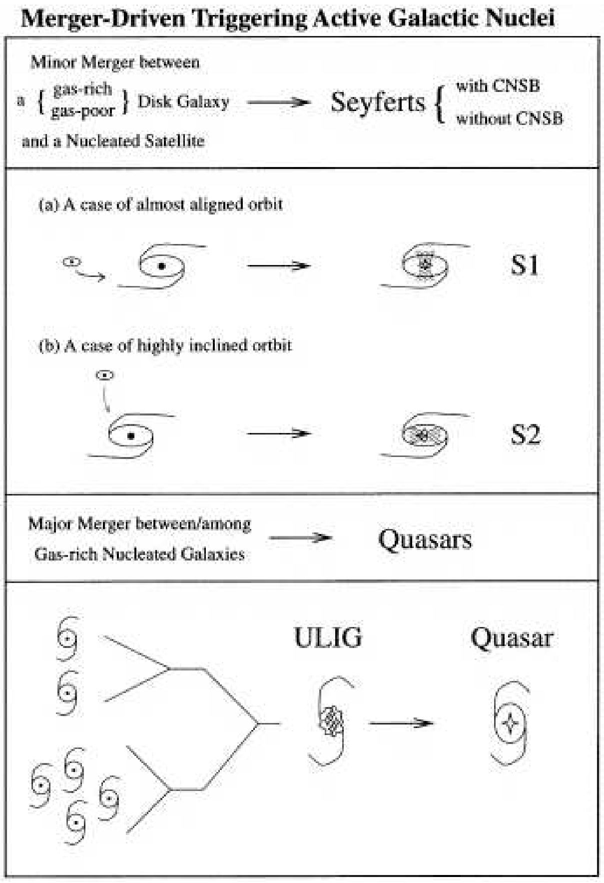

Figure 1.3: A possible merger driven unified scenario for AGN triggering (from Taniguchi 1999). Note ULIG =Ultra luminous infrared galaxy and CNBS= circumnuclear starburst.

pressure or accreted as fuel onto their central engine (Colina et al. 2001b).

Bars as a Fuelling Method

Coherent non-axisymmetric gravitational potentials within the discs of galaxies are often cited as methods by which mass can be transfered from the outer parts of a galaxy into the inner regions where it can be used as fuel for galactic activity. Spiral arms and bars are non-axisymmetric gravitational potentials which perturb gas and stars from circular orbits (Friedli & Benz 1993; Laine et al. 2002). These bars can transfer the angular momentum from the gas and stars into gravitational torques promoting inter-cloud interactions. As a consequence of this the gas will lose its angular momentum and travel down the bar towards the central region of the galaxy (Shlosman, Frank & Begelman 1989).

Galactic bars provide a method of transporting mass into the central regions of galaxies, but at the very centres of galaxies near to the AGN activity, bars can become unstable as the infalling mass accumulates (Norman et al. 1996; Shlosman et al. 1989). These instabilities can lead to the eventual destruction of bar potentials and ultimately limit the ability of bars to fuel AGN. Observations of near-by barred galaxies (Laine et al. 2002) have shown that a significant percentage of the Seyfert host galaxies display multiple bar potentials and in particular display small-scale *nested* bars. Nested bars may provide a means by which gas can be fed to within $\sim$1 pc of AGN but these may also be short lived, transient features (Maciejewski & Sparke 1999). More recent observations have shown that nested bars contain a reasonable quantity of molecular gas and have been detected in the near-IR lines of H_2 (e.g. Forbes, Kotilainen & Moorwood 1994; Kotilainen et al. 2000; Maiolino et al. 2000). Further observations of the gaseous content of these bars and nested bars is needed if their role in the fuelling of galaxy activity is to be more fully understood.

At present, it is still unclear from observations what role bars play in active galaxies. Naively we would be expect to see an excess of active galaxies that contain bars and nested bars compared to the population of 'normal' field galaxies. Some observations do suggest that there is some excess of bars in active galaxies, notably Laine et al. (2002), but other samples such as Regan & Mulchaey (1999) and Martini & Pogge (1999) find little or no evidence for such a correlation. It is clear that the physical processes that are involved in bars can drive gas into the central region of galaxies efficiently and that nested bars may help to transport this gas to within a few parsecs of the nucleus. These processes will undoubtly help to trigger and fuel both starburst and AGN activity but are unstable and in filling the central region with material may cause their own destruction. Consequently, it maybe that we do not observe large scale or nested bars in all active galaxies, not because they were not integral in the fuelling and formation of the activity, but because they no longer exist by the time the activity in the galaxies is observed.

1.4 Neutral Gas in Galaxies

Within galaxies neutral gas is detected in many forms, including atomic and molecular species. All of these species provide valuable tracers of the kinematics and distribution of the interstellar medium, ISM, of galaxies. As has been previously stated gas is also a key component of active galaxies because of the role that it plays in fuelling and obscuring nuclear activity. Of the observable components of the neutral ISM, neutral hydrogen, HI, is the most abundant gas species and one of the most easily observed via its $\lambda\,21$ cm transition line.

1.4.1 Neutral Hydrogen Studies & The 21 cm Line

In the 1950's the first observation of the $\lambda\,21$ cm spectral line of neutral hydrogen by Ewen & Percell (1951) lead to one of the most important astronomical tools in the study of the interstellar medium (ISM).

All atoms and molecules will emit or absorb radiation of specific energies, or wavelengths, due to transitions between their atomic or molecular states. In the case of neutral hydrogen one such transition emits or absorbs electromagnetic radiation at a frequency of 1420.405 MHz, corresponding to a wavelength of 21 cm, hence the commonly used terminology.

The 21 cm line is produced by a 'spin-flip transition' between hyperfine energy levels of the hydrogen atom. The spin vector of the electron within the hydrogen atom can exist as either parallel or anti-parallel relative to that of the proton. When the spin vector of the electron flips from being in the higher energy parallel state to the lower energy anti-parallel state the excess energy is released in the form of a photon with a wavelength of 21 cm. The chance of this transition is extremely low with a probability of spontaneous emission of $2.85\times10^{-15}\,\mathrm{s}^{-1}$ (i.e 1 photon in every 11 million years). As a result most transitions between these states are collisionally initiated rather than via a spontaneous radiative emission process.

The population of the upper, parallel, energy state (F=1) is maintained by collisional excitation. This implies that the radiation is thermal with the excitation (or spin) temperature $\mathrm{T_s}$ of the gas defined as,

$$\frac{\mathrm{N}_2}{\mathrm{N}_1} = \frac{g_2}{g_1}.\mathrm{e}^{-(\frac{h\nu}{k\mathrm{T}_s})} \tag{1.1}$$

where N_2 and N_1 are the populations of the upper and lower energy states, g_2 and g_1 are their statistical weights, ν is the frequency and k is the Boltzmann constant.

Although a large number of HI studies have observed the 21 cm line in emission, it is also possible to observe the 21 cm line via absorption against any bright radio continuum source. HI absorption will occur when an incident photon strikes an HI atom in the lower energy state and causes the electron vector spin to flip, absorbing the photon and transferring the atom to the higher energy state. The result will be that the flux density of the background radio continuum will be absorbed at a certain frequency and thus will be observable as an absorption line.

H I in Emission

Observations of H I in emission have proved, to be an invaluable astronomical tool in ISM studies both in our galaxy and in external galaxies. Highlights have included direct observations of the affect that interactions have on galaxies and their constituents upon scales of 10s→100s of kiloparsecs from the galaxy centres (see for example Hibbard et al. 2001[1]). Arcsecond angular resolution studies of individual objects (e.g. Mundell et al. 1999; Higdon et al. 1998; Liszt & Dickey 1995; Bosma 1981) have traced spiral patterns, deviations from circular orbits and bar potentials that may contribute to the feeding of gas and dust toward the central regions of active galaxies.

Although H I emission observations have numerous, valuable, attributes they do have one significant draw back. With existing radio interferometers it is impossible to observe the H I spectral line in emission at angular resolutions smaller than a few arcseconds which implies that, with the exception of our own Galaxy and the LMC/SMC, these observations are limited to linear scales of hundreds of parsecs or greater. This limit is primarily due to the sensitivity of radio receivers and hence the brightness sensitivity of existing interferometers. The flux density, S_ν of a body with brightness temperature $\mathrm{T_B}$ is

$$S_\nu = \frac{2k\mathrm{T_B}\Omega}{\lambda^2} \tag{1.2}$$

where Ω is the solid angle subtended by the body, λ is the observing wavelength and k is the Boltzmann constant. The Rayleigh-Jeans law here conspires against high resolution observations of λ21 cm H I emission. At present the sensitivity of

[1] A 'living' electronic gallery of examples of H I emission observations, showing the effects of mergers and interactions upon the gas in galaxies is available at http://www.nrao.edu/astrores/HIrogues/. This forms a dynamic electronic version of the work initially presented by Hibbard et al. (2001).

radio receivers is limited to $\sim$0.5* mJy bm^{-1}, which at a wavelength of $\sim$21 cm and a source brightness temperature of $\sim$100 K (see section 1.4.1) limits the angular resolution of these observations to $\sim$5-6 arcsec without prohibitively long integration times. This resolution, although ideal for studying large scale structures in galaxies is insufficient to resolve sub-arcsecond structures in the nuclear regions of active galaxies.

HI in Absorption

One solution to the problem of HI emission studies inability to observe at high resolutions is to observe the neutral gas via absorption. By observing the 21 cm line of neutral hydrogen against a high brightness temperature radio continuum source observations are only limited by the brightness temperature of the background source. In active galaxies the radio continuum emission can have brightness temperatures as high as $T_B \sim 10^5 \rightarrow 10^6$ K thus making them ideal targets for such observations. This observational technique is thus only limited by the angular resolution of the radio interferometer used which, for example, with MERLIN is $\sim 0\farcs2$. Although absorption line studies do have some other limitations compared to emission line studies, insofar as they require the presence of extended background radio continuum, they do also provide an advantage as they give unique information on the line of sight geometry of the neutral gas and continuum emission (i.e. the absorbing gas must lie in front of the radio continuum source).

*This is the typical sensitivity expected for an observations at $\lambda \approx$21 cm with a bandwidth of $\sim$100 kHz and an integration time of $\sim$ 18 hours.

Column Densities and Spin Temperatures of Absorbing HI Gas

From observed neutral hydrogen absorption spectra the velocity, opacity and column densities of the absorbing gas can be derived. The neutral hydrogen column density can be related to the observed HI spectrum by

$$N_{\rm HI} = 1.823 \times 10^{20} \int \tau \, {\rm dv}({\rm T_s}/100 \ {\rm K}) \ {\rm atoms \ cm^{-2}}, \tag{1.3}$$

where $\rm T_s$ is the gas spin temperature, v is in units of km s^{-1} and τ is the HI optical depth recorded against the background continuum (Gallimore et al. 1999). The population of the hyperfine energy levels in the hydrogen atom determines the spin or excitation temperature, $\rm T_s$, of the gas and is a vital scaling factor in the calculation of the true value of the column density (see equation 1.3). This value is controlled primarily by three physical processes within the gas: collisions, pumping by Lyα photons and absorption of 21 cm radiation (Field 1959a, 1959b, 1959c) these can be represented by the equation,

$$\rm T_s = \frac{T_R + \mathit{y}_c T_k + \mathit{y}_L T_L}{1 + \mathit{y}_c + \mathit{y}_L}, \tag{1.4}$$

where $\rm T_R$, $\rm T_k$ and $\rm T_L$ are the brightness temperature of the 21 cm continuum, the kinetic temperature of the gas and the temperature of the Lyα with the coefficients $y_{\rm c}$ and $y_{\rm L}$ representing the efficiencies of each heating process. In high density regions it is expected that collisions will provide the dominant heating mechanism, hence $\rm T_s$ will approach $\rm T_k$ (see Dickey et al. 1978; Payne et al. 1983; Liszt et al. 1983; Braun 1997). However, when the neutral gas is in close proximity to a bright continuum source, such as an AGN, it is apparent that both radiative 21 cm absorption and Lyα photons will become increasingly important in the determination of the excitation temperature (e.g. Gallimore et al. 1999; O'Dea et al. 1994). Gallimore et al. (1999) found that although the spin temperature of HI gas will be affected, to some extent, by radiative absorption processes and Lyα pumping, it will still be dominated by collisional processes for areas where $N_{HI} \gtrsim 1000\,\mathrm{atoms\,cm^{-3}}$, thus the HI gas will be thermalised ($T_s \approx T_k$) in dense clouds. In gas clouds irradiated by a nearby AGN, the cold atomic hydrogen is expected to have kinetic temperatures of approximately 100 K (Maloney et al. 1996). It should be noted that a significant amount of hydrogen can still remain neutral in regions where the kinetic temperature (and the spin temperature) have risen to a few 1000 K (Maloney et al. 1996). As a result by assuming that $T_s \approx 100$ K when calculating HI column densities will only ever provide a lower limit on the true column density. Although, it should also be noted that HI absorption will preferentially detect cooler parts of neutral gas clouds since,

$$\tau \propto (T_s \Delta V)^{-1} \tag{1.5}$$

hence detected HI absorption clouds are more likely to have $T_s \sim 100$ K than a few thousand Kelvin.

1.4.2 Neutral Hydrogen Absorption Studies of Active Galaxies

The first detection of neutral hydrogen absorption from gas within an extra-galactic source (Centaurus A) was made by Roberts (1970). Since this first detection of extra-galactic HI absorption there have been numerous further studies using large single dish instruments (e.g. Heckman et al. 1978; Mirabel 1982; Heckman et al. 1985; Baan & Haschick 1983; Mirabel & Sanders 1987; Mirabel & Sanders 1988). These single dish samples of HI absorption in galaxies were all limited to arcminute angular resolutions. Consequently these observations were often contaminated by HI emission from the galaxies they were observing and provided little spatial information about the gas distribution. However, these surveys did observe HI absorption with column densities and line widths that implied the absorbing gas was situated in the central parts of these galaxies, thus invoking the need for much higher resolution studies.

In the 1980's and 1990's the wide spread use of radio interferometers, such as the Westerbork Synthesis Radio Telescope, WSRT, and in particular the Very Large Array, VLA, enabled decimetre observations of absorption lines to be made at resolutions of up to an arcsecond (e.g. Shostak et al. 1983; Baan & Haschick 1983; Dickey 1986; van Gorkom et al. 1989). This increased resolution, not only provided spatial information about the gas distribution, but also reduced the contamination caused by HI emission detected from the outer parts of the sources. The success of instruments such as the VLA and WSRT in these observations has continued to be utilised in studying HI absorption against active galaxies both to provide high sensitivity observations of individual sources (e.g. Pedlar et al. 1992; Gallimore et al. 1994) and observations of larger samples of HI absorbing galaxies (e.g. sample of Seyfert galaxies by Gallimore et al. (1999) and radio galaxies by Morganti et al. (2001a)). However, these observations still lacked the sub-arcsecond resolution required to fully study the structure of the neutral gas on scales desirable for investigating its role in obscuring the AGN.

The first HI absorption observations using the Multi Element Radio Linked Interferometric Network (MERLIN) were made by Mundell et al. (1995). These observations exploited the ∼0.2 arcsec angular resolution of MERLIN to study HI within a few parsecs of the Seyfert nuclei of NGC 4151, providing a large increase in resolution over previous VLA observations of this source by Pedlar et al. (1992). The high resolution ($\sim0\farcs2$) and sensitivity ($\sim0.3\,\mathrm{mJy\,bm^{-1}}$) of MERLIN has enabled neutral hydrogen absorption to be observed against background radio sources with flux densities as low as just a few $\mathrm{mJy\,bm^{-1}}$ (see for example Wills et al. (1998)) and on linear scales, in nearby active galaxies, of ∼10 pc.

The angular resolution of MERLIN not only provides the spatial information to obtain a far fuller picture of the gas distribution within galaxies on much smaller scales than the VLA but also removes contamination of any surrounding HI emission from the source. Furthermore, a much higher spectral dynamic range is required to detect HI absorption with instruments that have resolutions comparable to the VLA than is required for MERLIN. If the absorbing gas is distributed in a small unresolved area with a strong background continuum source, weak absorption lines may be swamped by the radio continuum signal. The order of magnitude increase in resolution of MERLIN compared to the VLA allows these small regions of absorbing gas to be further resolved, reducing any contamination by the background radio source. This results in a stronger line detection hence reduces the need for high spectral dynamic ranges. The combination of these two factors can be seen when MERLIN and VLA observations of the same source are compared. For example, Pedlar et al. (1992) used the VLA to observe HI absorption against the well–known Seyfert galaxy NGC 4151. They derived HI column densities of 6×10^{20} atoms cm^{-2} against the unresolved continuum source. However, latter MERLIN observations by Mundell et al. (1995) did resolve the radio continuum and found that the column densities derived by Pedlar et al. (1992) were an order of magnitude lower than those implied by their own observations.

Of course it is possible, with modern Very Long Baseline Interferometry (VLBI) techniques to further increase the resolution of this type of observation compared to that of MERLIN. Over past few years there has been an ever increasing number of results that have exploited HI absorption and VLBI techniques to image neutral gas against the cores of AGN on parsec scales. For example, van Langevelde et al. (2000) used the European VLBI Network (EVN) to observe HI in a gaseous disc of radius $\sim$6 pc surrounding the nucleus of the FR1 radio galaxy NGC 4261. They showed that the HI absorption coincided with a dust disc observed with the *Hubble Space Telescope* (*HST*). Several other examples of VLBI observations of HI absorption against radio-loud AGN (e.g. Taylor 1996; Conway 1999; Taylor et al. 1999b; Pihlström et al. 2000; Peck & Taylor 2002) have also detected neutral hydrogen with high opacities. However, fewer VLBI observations have been made of HI absorption against less radio luminous galaxies, such as ULIRGs. At present these have been limited to observations of compact starburst regions in Mrk 273 (Carilli & Taylor 2000) and Mrk 231 (Carilli, Wrobel & Ulvestad 1998). VLBI experiments with their milliarcsecond resolution are only really suited to observations of compact, high brightness temperature objects and resolve away extended lower brightness radio components. By combining VLBI observations with data from other instruments, such as MERLIN and the VLA, can provide the sensitivity to extended lower brightness radio emission that VLBI observations lack. Recent EVN plus MERLIN spectral line observation (e.g. Pihlström et al. 2001) have highlighted this technique as a method by which the flux density from extended areas of radio emission can be successfully preserved without significantly compromising the high angular resolution of VLBI experiments. Similar observations will allow VLBI HI absorption observations of more extended sources in the future.

At present, the most comprehensive single interferometric sample of Seyfert galaxies observed for 21 cm absorption was presented by Gallimore et al. (1999). In this survey Gallimore et al. used the VLA (A-array) to observe HI absorption against a radio flux-limited sample of 13 Seyfert-1 and -2 galaxies. Of these nine sources were detected to have HI absorption. From modelling these results, they concluded that the HI absorption in these Seyfert galaxies appeared to trace central absorbing discs of gas with sub-kiloparsec radial sizes. Additionally it was also observed, from this sample, that HI absorption was not generally detected against the Seyfert nuclei but more commonly seen against extended radio continuum components and that the 21 cm HI column densities did not correlate with those derived from X-ray spectroscopy. These observed characteristics were attributed to free-free absorption of Seyfert nuclei resulting in no 21 cm continuum emission reaching the neutral layer of the obscuring medium from the AGN.

MERLIN's intermediate resolution in between VLA and VLBI experiments makes it an ideal instrument for studying H I absorption against sources with structure sizes between $\sim 6''$ to $\sim 0\farcs15$. Although no surveys similar to Gallimore et al's have been made with MERLIN as yet it, has been used to make detailed studies of H I absorption in several Seyfert galaxies, including NGC 4151 (Mundell et al. 1995), NGC 3079 (Pedlar et al. 1996), Mrk 6 (Gallimore et al. 1998) and NGC 5929 (Cole et al. 1998b). In these observations H I was generally observed against the extended radio continuum structure of the Seyfert galaxy. Mundell et al. (1995) highlighted the necessity for sub-arcsecond angular resolution observations by imaging highly localised absorbing gas against a radio continuum knot close to the Seyfert core of NGC 4151. They concluded that the gas was part of a torus or ring, no thicker than 50 pc and were able to place a lower limit upon total H I mass in the area of $90\,M_{\odot}$. Against Mrk 6 Gallimore et al. (1998) found H I absorption against compact radio component approximately 400 pc away from the optical nucleus of the Seyfert source. It was concluded that this gas formed part of a kiloparsec scale disc that is exhibiting galactic rotation. Towards the Seyfert-2 galaxy NGC 5929 Cole et al. (1998b) observed H I absorption that appeared to be dynamically associated with the galaxy's rotation and coincident with a dust lane observed with *HST* images.

H I absorption studies using MERLIN have also been exploited to investigate the neutral ISM in several starburst and ULIRG galaxies. These have included M 82 (Wills et al. 1998), Mrk 273 (Cole et al. 1999) and Arp 220 (Mundell, Ferruit & Pedlar 2001). In particular, Wills et al. (1998) used MERLIN to study H I against 26 of the 33 supernovae detected in the prototypical starburst galaxy M 82. By measuring the H I velocities observed against these remnants and comparing these with observations of the molecular (CO) and ionised ([Ne III]) components, they were able to model the gas motions. In a latter paper they show that the gas motions were not the result of solid body rotation but were more consistent with gas moving in a galactic bar (Wills et al. 2000). Against the more extreme ULIRGs of Mrk 273 and Arp 220 the picture was somewhat less clear but by no means less interesting. Cole et al. (1999) resolved HI absorption against two out of three of the radio continuum components in Mrk 273. They observed broad absorption features against the most northern radio component of Mrk 273 which displayed several distinct spectral components compared to relatively narrow absorption seen against the south-eastern radio continuum component. Cole et al. (1999) concluded that the dynamics of the northern radio component, which is spatially associated with one of the two optical nuclei, were consistent with a rotation of a disturbed ring of neutral gas whilst the absorption against the south-eastern component was due to quiescent gas in a large scale dust lane. Against the double radio structure of the archetypical ULIRG merger galaxy Arp 220 Mundell et al. (2001) re-detected the extremely broad HI absorption seen against this source in previous single dish observations. They concluded that the HI they observed against the two radio components was consistent with the gas lying in two counter–rotating discs. It is assumed that the two radio components are the remnant cores of the two galaxy nuclei and that the two counter–rotating discs are dynamical residuals of these original merger progenitors.

Although there have been several MERLIN HI studies of Seyfert and more recently starburst galaxies, there have been few attempted observations of more radio-loud AGN, such as radio galaxies. One of the exceptions to this are the observations of the radio galaxy 3C 305 (Cole 1999; Jackson et al.submitted). Cole (1999) observed HI absorption against a highly localised area of the south-eastern radio lobe and jet of 3C 305. These observations have been extensively compared to *HST* observations of the source which has shown that this narrow localised HI absorption is spatially coincident with areas of strong optical extinction due to the dust lanes.

1.4.3 Comparisons with other Astronomical Observational Techniques

Although of course using a single observational technique such as HI absorption studies does provide a wealth of information about a particular component, such an approach does not provide a view of the whole picture. HI absorption provides essentially keyhole-like view of the neutral gas only along the lines of sight towards background radio continuum components. Hence, it is vital that these types of observations are put into some context with other techniques that probe the neutral ISM of galaxies.

The neutral gas within the central regions of active galaxies can be studied in a variety of ways other than HI absorption. These primarily consist of using X-ray emission to probe the column densities of gas obscuring an AGN, HI emission observations and molecular emission or absorption observations either at high angular resolutions via maser emission and/or molecular absorption of species such as OH and H_2CO, or via observations at millimetre wavelengths of molecules such as CO.

Additionally it is possible to probe some of the other components of the ISM in galaxies. These include absorption by dust in the optical and ionised gas through optical emission lines.

Unfortunately many of these observing techniques, with the exception of maser and some molecular absorption observations, are severely limited by the spatial resolution and sensitivity of the instruments that are currently available.

Molecular Gas

One of the most fruitful techniques, that is directly comparable to HI absorption investigations is the study of molecular gas. Molecular gas has been observed to be abundant in the centres of active galaxies and has been detected via collisionally excited emission, stimulated maser emission and in some cases absorption.

Maser emission from several molecular species such as OH, H_2CO and H_2O has been detected at radio wavelengths in active galaxies. Masers are normally observed from compact areas which have high brightness temperatures making them ideally suited to high angular resolution observations with radio interferometers (e.g. Miyoshi et al. 1995; Pihlström et al. 2001). However, maser observations have similar draw-backs to absorption studies since they only provide a limited view of the gas component along a few lines of sight towards the point from which the emission is stimulated. It is also unfortunate that maser emission is only observed in a relatively small number of sources further limiting comparisons with HI studies.

Using the similar techniques as employed in HI absorption studies it is possible to observe some molecular species (e.g. OH, H_2CO) via radio absorption lines. Numerous active galaxies have been observed in large single dish samples to have spectra containing absorption due to these species, however few of these have been followed up with interferometric observations. These lines have been observed interferometers such as MERLIN and the VLA against some sources (e.g. Schemelz, Baan & Haschick 1987; Baan, Rhoads & Haschick 1992), although these absorption lines are normally weaker than the HI line making these observations more difficult. Additionally, observations of certain species, such as H_2CO, can be limited by diminishing radio continuum flux densities at higher frequencies.

The molecule lines of CO can be observed in the millimetre wavelength range via emission and occasionally absorption. These observations allow the molecular content of CO, a tracer of H_2, to be mapped in a few galaxies. At the present time these observations are largely limited by the resolution and sensitivity of the instrumentation. The highest angular resolutions currently achievable are $\sim 1''$ (e.g. Tacconi et al. 1996; Evans et al. 1999).

At present molecular emission observations have only a limited value in comparison with high resolution HI absorption studies because of the large disparity in the angular resolutions they sample and, in the case of maser and decimetre absorption lines, the relatively limited number of sources that can be observed. However, these observations do provide considerable information about the dense molecular gas within active galaxies. It is thought that the molecular component in galaxies is likely to be associated with the neutral hydrogen component, thus these observations need to be considered when making interpretations of HI observations. The comparison with high resolution molecular absorption and maser observations with high resolution HI absorption experiments is, however, easier to make. The observing techniques and resolutions of these two methods are directly comparable. Such comparisons are therefore invaluable in understanding the relative distributions of these two components and how their environment affects them differently.

Dust

There is without doubt a distinct connection between dust and the location of neutral gas in galaxies. This has been proved by several high resolution HI studies of individual sources (e.g. 3C 305 Cole 1999; Mrk 273 Cole et al. 1999; NGC 4261 van Langevelde et al. 2000). In addition dust plays an important role in relationship between different components of the ISM, such as providing nucleation sites for the formation of molecules and shielding of them from photo-disassociating radiation. Additionally dust is a crucial component in the obscuration of AGN.

Present instruments, in particular the *HST*, now provide a method by which this component can be observed at sub-arcsecond resolutions, directly comparable to MERLIN. Although in the optical it is often impossible to view the centres of active galaxies due to the dust obscurations itself, the dust that causes this obscuration is obviously situated along the same lines of sight as the HI gas that we can observe in absorption and thus is directly comparable.

X-ray Studies

Observations of the X-ray emission from the centres of active galaxies can provide a measure of the absorbing gas along the line of sight to the background X-ray source. The advent of the current X-ray observing satellites, *Chandra* and *XMM*, has provided high sensitivity, sub-arcsecond angular resolution imaging of X-ray emission. In turn this has now allowed some imaging spectroscopy on sub-arcsecond scales against active galaxies (e.g. Young, Wilson & Shopbell 2001). These X-ray observations measure the column densities of the warm partially, ionised gas component via photo-electric absorption of the background X-ray continuum at energy levels of $\sim$ few keV. In order to calculate the gas column densities this method requires assumptions about the shape of the X-ray continuum spectrum and the relative abundances of the molecular species and dust compared to the neutral hydrogen.

It has been generally found that the X-ray derived column densities exceed the HI column densities observed via radio absorption techniques by an order of magnitude or more. These excessively high column densities may be due to errors in the assumed ratio of molecular and neutral gas implying that the majority of the neutral gas is in fact in a molecular form or that the X-ray background source is heavily obscured by dust. It is also likely that the cold neutral hydrogen that is observed in radio experiments is not cospacial with the warmer partially ionised gas that X-ray experiments sample thus explaining this observed discrepancy.

1.5 This Thesis

Over the past few years it has become increasingly obvious that sub-arcsecond resolution observations of the neutral components of the ISM in active galaxies are essential if we are to understand their gas dynamics and fuelling mechanisms. Sub-arcsecond resolution observations of the radio continuum, optical, infrared and recently X-ray emission in galaxies are now routinely available. These sub-arcsecond resolution observations have demonstrated the importance of the physical processes that occur at these scales. Theory has also concluded that gas is a vital component in both fuelling and obscuring AGN on linear scales that extend down to the AGN itself.

Although there are several techniques that can be used to observe neutral gas in galaxies, many of these have limitations on the angular resolution they can achieve. One of the main exceptions to this limitation is the study of neutral gas with radio interferometers via absorption lines. This thesis will therefore concentrate upon exploiting this technique via studying the λ21 cm line of neutral hydrogen in absorption against a variety of active galaxies.

Motivation

The motivation for this thesis is to provide detailed, high angular resolution investigations of the distribution and kinematics of the neutral hydrogen within central regions of several nearby active galaxies and significantly increase our understanding of the role of gas in these galaxies and their activity. The galaxies that have been observed for this thesis do not form a complete sample of any particular class of active galaxy. These sources consist of three different types of active galaxies; Seyfert, radio and luminous infrared galaxies, with the individual sources selected on the basis of their observational suitability. Typically, the criteria used to select these sources were extended radio continuum at the resolution of the interferometer used, evidence for neutral gas (either emission or ideally absorption) and redshift.

The particular intentions of these studies are (1) to extend our understanding of the contribution that neutral gas plays in the obscuration of AGN in relation to 'dusty' torus models, (2) to investigate the fuelling mechanisms that enable the transportation of gas into the central regions of active galaxies and (3) to provide a considerable increase in the number of active galaxies in which detailed, high resolution observations of the neutral ISM have been made. One of the long term goals of this project is to produce a statistically meaningful sample from which more general conclusions about the role of neutral gas in activity can be drawn from.

Structure

The following chapters of this thesis will be organised as follows. In chapter 2 the methods involved in radio interferometry will be discussed with particular reference to the instruments used for observations presented in this thesis and the data reduction techniques employed. In the following four chapters the scientific results obtained are presented. These four chapters will discuss individual sources or groups of associated sources, initially starting with the radio galaxy 3C 293 followed by the Seyfert galaxies NGC 7674 and NGC 7469 then a selection of luminous infrared galaxies with particular emphasis on the prototypical LIRG merger NGC 6240. The general theme will be detailed discussions of individual galaxies starting with the most radio-loud, AGN dominated sources and progressing into the starburst/AGN dominated luminous infrared galaxies. General conclusions regarding these results will be presented in the final chapter along with some future prospects for this field of research.