Chapter 1

Active Galactic Nuclei

Galaxies occur in a variety of shapes and sizes. Most galaxies contain a super-massive black hole at their centre (Richstone et al. 1998). A super massive black hole refers to a black hole with mass, $M_{BH} > 10^6 M_\odot$ (Jogee 2006). For most galaxies, this black hole is quiescent, so no material is accreting onto the black hole. However, in some galaxies, material accretes onto the central black hole causing the galaxy to become active (Lynden-Bell 1969; Rees 1985; Osterbrock 1993). This accretion releases large amounts of energy in a small compact area around the black hole, making these galaxies some of the brightest objects in the Universe. These galaxies are called Active Galactic Nuclei (AGN).

The mass of the accreted material is converted into energy; the rate at which the energy is emitted gives the rate the energy is supplied via accretion to the nucleus. In a typical AGN, the nucleus is brighter than all the stars by a factor of 100 (Peterson, 1997). The luminosity of the AGN is determined by the rate at which energy is emitted by the nucleus, and is given by Equation 1.1

$$L = \eta \dot{M} c^2 \tag{1.1}$$

where η is the efficiency factor (which depends on the nature of the accretion disk; Jogee 2006), $\dot{M}$ is the rate of mass accretion, and c is the speed of light. The mass accretion rate is given by Equation 1.2.

$$\dot{M} = \frac{L}{\eta c^2} \approx 1.8 \times 10^{-3} \left(\frac{L*}{\eta}\right) \mathrm{M}_{\odot}\mathrm{yr}^{-1} \tag{1.2}$$

where $L*$ is the characteristic luminosity of a field galaxy, $\sim 10^{44}$ ergs s^{-1}. Using an efficiency factor η =0.1 and $L = 10^{46}$ ergs s^{-1}, the mass accretion rate is $\dot{M} = 2$ M$_{\odot}$ yr^{-1}. The Eddington rate (the mass accretion rate needed to sustain the Eddington luminosity) is given by Equation 1.3.

$$L_E = \eta \dot{M}_E c^2 = 1.51 \times 10^{38} \frac{M}{M_{\odot}} \mathrm{erg\ s}^{-1} \tag{1.3}$$

where L_E is the Eddington luminosity and $M_{\odot}$ is a solar mass. The Eddington Luminosity is the luminosity at which the gravitational force matches the radiation pressure force. It follows from Equation 1.3 that the high luminosities seen in AGN must be created by a minimum central mass (Sparke & Gallagher 2000). This represents the maximum accretion rate possible for mass M (using a simple spherical accretion model), though this rate can be exceeded if the accretion occurs in a disk. For a bright quasar, the black hole must consume roughly 1% of the stellar mass of a bright elliptical galaxy or 10% of a bright spiral during their lifetime (Lake et al., 1999). The Eddington ratio is defined as $\lambda = L_{bol}/L_E$ where L_{bol} is the bolometric accretion luminosity of the system.

1.0.1 AGN Signatures

AGN show strong emission over a wide wavelength range, including radio, γ-ray and X-ray, where most galaxies barely radiate (Sparke & Gallagher 2000). One of the most prominent features in AGN spectra is the emission lines, which are stronger than those seen in stars and other galaxies. Sometimes these emission lines are broad, emitted from gas travelling at high speeds ($\sim$10,000 kms^{-1}), which is faster than the speed of stars orbiting within the galaxy.

AGN can be distinguished from inactive galaxies by their position on a Baldwin, Phillips and Terlevich (BPT) plot (Baldwin et al., 1981). This plot uses the ratios of lines ([OIII]λ5007/Hβ and [NII]λ6583/Hα) to classify objects by distinguishing between black-body and power-law ionising spectra.

1.0.2 Classes of AGN

There are different classes of AGN, mainly defined by their flux output as well as the emission lines seen and other data. Table 1.1 shows some of the properties associated with the different classes of AGN. Point-like refers to whether the host galaxy can be resolved, and variable indicates whether the output from the central black hole is variable.

Seyfert Galaxies

Seyferts galaxies show strong nuclear emission and prominent emission lines with an absolute magnitude in the V-band of $M_V > -22.5$ or $L < L^{10} L_\odot$ (Sparke & Gallagher, 2000). This magnitude boundary is simply a convention that has arisen and has no special meaning. The host galaxy containing the black hole at its centre can be spatially resolved due to the central source having a low enough luminosity to allow the host to be viewed. There are two types of Seyferts. Type 1 Seyfert galaxies have both narrow and broad lines within their spectra while Type 2 contain only narrow lines. Often the terms AGN, Seyferts and quasars are used interchangeably (Osterbrock & Mathews, 1986).

Quasars

Quasars are regarded as the brighter version of Seyfert galaxies, with an absolute magnitude in the V-band of $M_V < -22.5$ or $L > 10^{11} L_\odot$ (Sparke & Gallagher, 2000). Quasars are the most luminous objects known and have been found up to redshift of $z \sim 7$ (Mortlock et al. 2011). The quasar host galaxy cannot be spatially resolved due to the brightness of the central source. Some quasars (5-10%) are radio strong sources, with the majority being radio-weak.

LINERs

Low Ionisation Nuclear Emission Line Region Galaxies (LINERs) (Heckman, 1980) are similar to Seyfert Type 2s and show AGN signatures (González-Martín et al., 2009), but have strong low-ionisation lines (such as [OI]λ6300 and [NII]$\lambda\lambda$6548,5483). These objects are very common and dominate the population of active galaxies in the present universe and may be detected in nearly half of all spiral galaxies (Ho et al., 1994). These are distinguishable from HII regions by their larger values of [NII]λ6583/Hα and lower values of [OIII]λ5007/Hβ. This puts them in a distinct area on the BPT plot. LINERS may be different to other AGN due to complex absorbing structures along the line of sight (González-Martín et al., 2011).

Radio Loud and Quiet

AGN can also be split into radio loud and radio quiet objects. Radio loud quasars have powerful jets of material coming out from the central black hole, and are only found in elliptical galaxies. Radio quiet AGN do not have jets, have less radio emission, and are found in a variety of spiral galaxies. Radio loud galaxies can be split into broad line radio galaxies (BLRG) and narrow line radio galaxies (NLRG) which are analogous to Type 1 and Type 2 Seyferts respectively.

BAL Quasars

A sub-category of quasars is Broad Line Absorption quasars (BAL) which show broad absorption lines within the optical spectra, and are found in roughly ~10% of quasars. The line widths show evidence of high Doppler broadening in the ranges of 0.01-0.1$\times c$, the speed of light (Robson, 1996), which are indicative of massive outflows of material from the quasar centre (Hopkins et al., 2008). There is also a category of low-ionisation BAL (LoBAL), which make up only 1.5-2.1% of the entire quasar population (Dai et al. 2010). These quasars show absorption from low-ionisation lines such as MgII and FeII.

BL Lacs and OVVs

There are other AGN types, which can be grouped together due to strong similarities in their radio-loud flat spectra, the variability in the optical output, and are strongly beamed (Fan 1997), called BL Lac and OVV (Angel & Stockman 1980).

BL Lacs (originally thought to be variable stars) are high-luminosity Type 1 radio loud galaxies. It is believed these objects lie with their jets close to our line of sight as they show superluminal motion, evidence for synchrotron radiation within a cone, and are beamed towards the observers line of sight. Emission and absorption lines are very weak or absent in BL Lac spectra, leaving the spectrum featureless. They also have strong and rapid variable radiation (on the time-scale of hours and longer).

Optically violent variable (OVV) quasars are similar to BL Lacs. OVV quasars are also radio loud and are very rare, but they tend to show prominent broad emission lines on the spectra and are high luminosity sources (Basu, 2001, and references therein). The flux output is highly variable (in the orders of magnitudes) and varies erratically, with time-scales ranging from days to years.

ULIRGs

Luminous or Ultra-Luminous Infra-red galaxies (LIRGs/ULIRGs) are believed to be the dust-enshrouded phase of a quasar (Sanders et al., 1988a,b), emitting most of their energy in the infra-red with luminosities of $L_{IR} > 10^{12} L_{\odot}$ (Meng et al., 2010). These galaxies show evidence of strong interactions (most likely the advanced stages of a major merger) (Rich et al., 2011; Krolik, 1999), and are roughly as numerous as AGN of comparable luminosity (Sanders & Mirabel, 1996). More than 95% of ULIRGs show evidence of morphological disruptions such as tidal tails, double nuclei, bridges and overlapping disks (Veilleux 2001). It is believed ULIRGs may be the first stages of a quasar (Meng et al., 2010) and may evolve into elliptical galaxies. Once the dust surrounding the AGN has been consumed or swept away, the optical AGN is revealed.

Table 1.1: Classes and properties of AGN.

	Point like	Broad emission lines (FWHM$\sim 10^4$km s^{-1})	Narrow emission lines (FWHM$\sim$ 400 km s^{-1})	Radio	Variable (ergs s^{-1})	Typical L_{bol}
Quasars	Yes	Yes	Yes	Yes	Yes	$10^{46} - 10^{47}$
Seyfert Type 1	Yes	Yes	Yes	Weak	Some	$10^{42} - 10^{44}$
Seyfert Type 2	No	No	Yes	Weak	No	$10^{42} - 10^{44}$
LINERs	No	No	Yes	No	No	$10^{41} - 10^{42}$
BL Lacs	Yes	No	No	Yes	Yes	$10^{44} - 10^{46}$
OVV	Yes	Yes	Yes	Yes	Yes	$10^{44} - 10^{46}$

1.1 Structure

Figure 1.1 shows the structure of an AGN (Urry & Padovani 1995; annotated by M. Voit).

The centre of the AGN consists of a super massive black hole, which is very hot and luminous and photoionises the surrounding area (Osterbrock & Mathews, 1986). The size of the accretion disk (for a $10^8 M_\odot$ black hole) is roughly the size of our solar system. Surrounding this central source is the broad line region (BLR) associated with broad emission lines. Beyond this lies the narrow line region (NLR).

AGN appear to be axially rather than spherically symmetric. There is likely to be an optically thick torus of dust around the quasar obscuring the unresolved radiation. This permits the radiation to only escape along the torus axes.

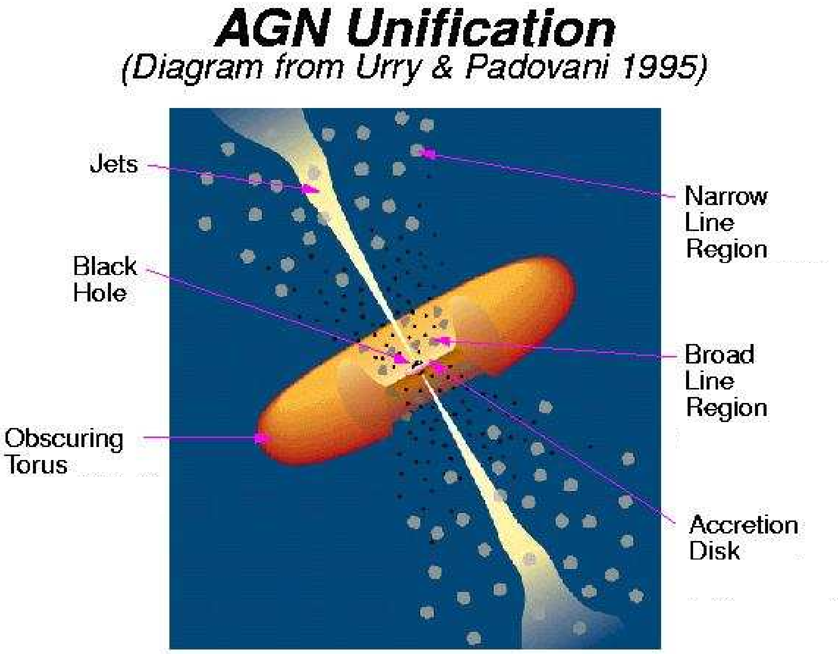

Figure 1.1: The structure of an AGN is shown in this figure, highlighting different regions. Diagram from Urry & Padovani (1995); annotated by M. Voit.)

The Broad Line Region (BLR) lies beyond the central black hole and accretion disk. Lines emitted from this region typically have a full-width-half-maximum (FWHM) of ~10,000 kms^{-1}, although can be up to 15,000 kms^{-1} (Robson, 1996). The BLR has a typical radius of $\sim$0.07-1.0 pc (Osterbrock & Ferland, 2006) and is comprised of solar-like abundances. The exact dynamics and kinematics of the BLR are still not clear due to the inability to spatially resolve this region. The density is estimated to be 10^9 to 10^{10}cm^{-3}.

The BLR is comprised of a number of distinct optically thick clouds, the energy source for which is photoionisation by the continuum radiation from the central source (Peterson, 1997). Most of the emission from the BLR arises from these clouds, although they occupy only a small fraction of the volume of the BLR and are assumed to be arranged in spherical shells around the central source. There are estimated to be around 5×10^4 clouds in the BLR, with radii of $400R_{\odot}$.

The Narrow Line Region (NLR) lies outside the BLR at 10-100 pc and is the largest spatial scale where ionising radiation from the central source dominates. The NLR also lies outside the dust torus. This region is several orders of magnitude more massive than the BLR (although the emission is often comparable). The FWHM of lines can lie between $200 < \Delta z < 900$ kms^{-1}, though most lie within 350-400 kms^{-1}.

Like the BLR, the NLR is also clumpy in nature, containing clouds of gas which move at a slower speed which produces narrower spectral lines than seen in the BLR. This region has electron densities between 10^2 cm^{-3} to 10^5 cm^{-3}, and temperatures 10,000 to 25,000 K, with an average of 16,000 K (Koski, 1978).

The torus is a thick band of obscuring material around the central source but inside the NLR so the BLR is hidden (Konigl & Kartje, 1994; Elitzur & Shlosman, 2006). This allows the AGN radiation to only escape via the torus axes, defined by ionisation cones. The dust in the torus is likely to be in the form of high-density clumpy clouds (e.g. Krolik & Begelman, 1988; Nenkova et al., 2002; Deo et al., 2011), containing 10^9 M$_{\odot}$ of dust and molecular gas, and most of this material will be very hot ($\sim$1000K). The torus is a few hundred pc across, with the central torus hole being a few pc. This allows the central engine and the BLR to be obscured unless viewed face-on. This torus is essential for the unification models of the varying AGN types, which uses the theory that the AGN are all similar, but simply viewed from different angles (Antonucci, 1993).

1.2 Radio sources

Radio emission is created by synchrotron radiation, when relativistic electrons interact with a magnetic source and lose their energy via radiation. In AGN, this is created by outflowing plasma which produces bow shocks when it collides with the ambient NLR gas. One way of estimating the strength of the radio sources is using the radio optical flux at 6 cm (5 GHz) and 4400Å (680 THz), R_{r-o}. A radio quiet quasar (RQQ) has $0.1 < R_{r-o} < 1.0$, whereas a radio loud quasar (RLQ) has R_{r-o} >10 (Kellermann et al., 1989).

Radio loud quasars are only a small proportion of the AGN population except at the high end of the luminosity distribution. It is possible quasars with radio axes close to the plane of the sky are not detected as quasars but as radio galaxies. It is also thought radio quiet quasars may be the remnants of radio loud quasars (Marecki & Swoboda, 2011).

It has been proposed that the two radio types have different black hole spins, with the radio loud quasars having high spin black holes and radio quiet AGN having lower spins (Sikora et al., 2007; Wu et al., 2011). RLQ and RQQ reside in different galaxy host morphologies with radio loud AGN lying in early type red galaxies (Ledlow & Owen, 1996), and RQQ lying in disk galaxies (Lawrence, 1999).

1.3 X-ray sources

The most common characteristic of AGN is that they are all X-ray bright sources, a fact which is used to find radio-quiet AGN in surveys. The X-ray emission comes from the central core region and extends to <1 pc (Elvis et al., 1978). X-ray surveys are also very useful in finding quasars and AGN which are optically obscured by dust, as the X-ray regime is not as affected by dust. This wavelength is more sensitive to less luminous AGN compared to using optical selection.

1.4 Host galaxy

Most Seyferts are hosted by spiral galaxies, and tend to be (though are not always) early-type spirals. Generally, radio quiet galaxies and Seyferts are found in disk galaxies, while radio loud and broad line radio galaxies (BLRGs) are found in elliptical galaxies (Lawrence, 1999). Georgakakis et al. (2009) state that disk-dominated host galaxies contribute 30 $\pm$ 9 % of the total AGN space density at $z \sim 1$.

Irregular morphological features in the host galaxies are often linked to tidal interactions. It is more difficult to assess the morphology of quasar hosts due to the brightness of the central source overwhelming the starlight from the host galaxy. However, not all quasars are point-like sources and in low redshift quasars, about 50% of hosts show evidence of morphological peculiarities such as tidal features (Peterson, 1997). The host galaxy luminosity correlates with the quasar luminosity (Lawrence, 1999) with brighter AGN found in more luminous galaxies.

The colours of the host galaxies are generally consist with their morphological type. Though the colour distribution has been seen to be dependent on the influence of large scale structure (on the scales of $\sim$10 Mpc) (Silverman et al., 2008). Silverman et al. suggest that AGN prefer bluer hosts at $z > 0.8$ than AGN at $z < 0.6$. It has also been suggested that the AGN has an impact on the host galaxy by halting the star formation due to AGN feedback (e.g. Power et al., 2011; Blecha et al., 2011).

1.5 Unification theory

Most of the work in unification theory focuses on the morphology of the AGN and the angle at which the AGN is viewed. AGN will appear different when viewed from different angles, because of the dust torus preventing emission being seen from certain areas. Table 1.2 shows the types of AGN seen when viewed from different angles.

Table 1.2: AGN types with respect to the orientation of how they are viewed (Peterson, 1997).

Radio	Orientation	
Properties	Face-on	Edge-on
Radio Quiet	Seyfert 1	Seyfert 2
	QSO	FIR galaxy?
Radio Loud	BL Lac	FR I
	BLRG	NLRG
	Quasar/OVV	FR II

Figure 1.2 shows an example of how different types of AGN can be found by viewing the AGN from different angles. FRI galaxies are weak radio sources with a bright centre and decreasing surface brightness. FR2 are more luminous radio galaxies, are much more powerful (occurring on scales of kpc) and have steep radio emission found in the inner regions (Hughes, 1991). FR stands for Fanaroff and Riley who first classified these radio galaxies (Fanaroff & Riley 1974). FSRQ and SSRQ stand for flat-spectrum and steep-spectrum radio quasars, respectively.

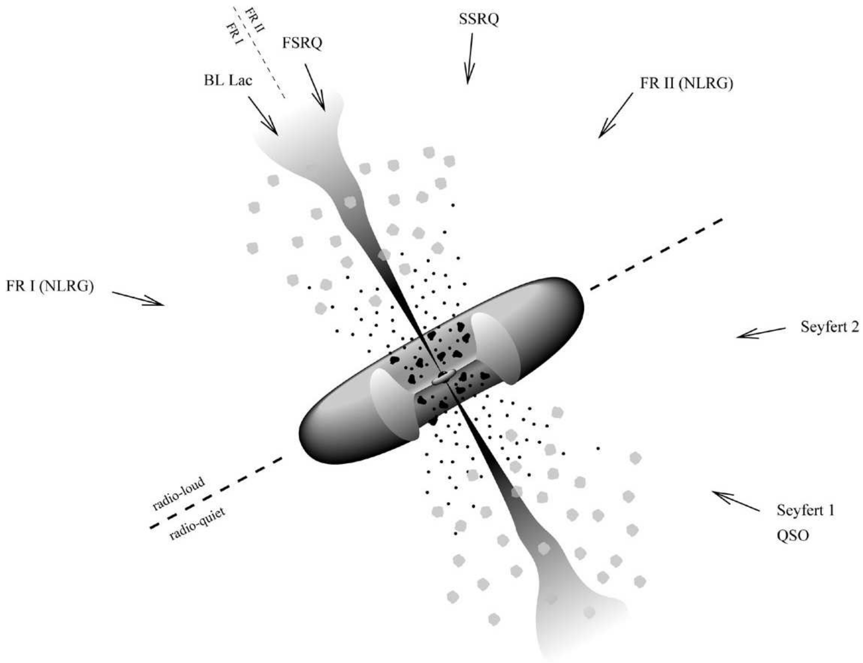

Figure 1.2: The AGN types found by viewing the AGN at different angles (Torres & Anchordoqui, 2004).

The main difference between Seyferts and quasars is the luminosity of the central source. The Seyfert Type 1 and Type 2 are thought to be the same objects, viewed from different angles (Antonucci, 1993). At least some Seyfert Type 2s are definitely Seyfert Type 1 with an obscured BLR. Spectra from the narrow line region are indistinguishable between Seyfert Type 1 and 2. The torus must block out 3/4 of the sky seen by the central source (Peterson 1997), as estimated from the number of Type 1 and Type 2 Seyferts. Evidence for a torus has been found in other wavelengths. Corral et al. (2011) looked at absorption in X-ray spectra and found larger amounts of intrinsic material for Type 2 than Type 1, which, if this is a line-of-sight effect, suggests the presence of a dust torus. Also all classes of Seyfert have been found to show the same nuclear continuum (Ricci et al., 2011).

However, it is likely that not all Type 2s are Type I viewed from a different angle, and the unification model breaks down. All quasars (high luminosity AGN) have Type 1 spectra. If all Type 2 were Type 1 viewed from a different angle, we would still expect some quasars with Type 2 spectra. (The reason we do not could be because high luminosity sources either do not have an obscuring torus or the torus is thin.) Quasars with Type 2 spectra could exist but so far have been classed as far-infra-red galaxies (FIR), which have a quasar-like luminosity and narrow line spectra. Also the continua from Type 2 Seyferts are not generally polarised which suggests the absence of a scattering medium, which was suggested should be seen. In the X-ray, the fraction of exceptions to the unified model was found to be 5% (Corral et al., 2011).

1.6 Fuelling mechanisms

The main problem in fuelling a quasar is moving the material from further out in the galaxy into the central parsec and removing the angular momentum of the material (Peterson, 1997).

The specific angular momentum of fuel ($L = v \times r$) at the last stable orbit of the black hole of mass, M_8 ($10^8 \mathrm{M}_\odot$), is several times $10^{24} \mathrm{M}_8$ cm^{2}s^{-1}. However, material in the galaxy's disk, with an orbit of 10 kpc, has angular momentum of several times 10^{29} M_8 cm^{2}s^{-1} (Jogee, 2006). Therefore, the material needs to be moved into the centre of the galaxy and its angular velocity must be reduced for it to be able to join the accretion disk which has a small radius.

There are various suggestions for fuelling an AGN, which may produce different luminosities and be dominant at different cosmic times and in different environments. For example, major mergers offer the most plausible mechanism for the triggering of brightest quasars, and dominate AGN evolution at early times ($z = 2 - 3$). At later times, the main fuelling mechanisms are more likely to be secular processes (such as bar instabilities) and minor mergers (van Breukelen et al., 2009; Cisternas et al., 2011; Ryan & De Robertis, 2010).

Different mechanisms may also be dominant in different environments.

1.6.1 Mergers

There are two types are mergers: major and minor.

A major merger is often described as the main method for fuelling AGN. This refers to the merger of two disk galaxies with a mass ratio of 3:1 or less. These mergers can induce a large scale inflow of gas ($\sim$a few percent of the galaxy's gas) into the inner kpc and cause starbursts and AGN activity (Kauffmann & Haehnelt, 2000). This is believed to be the main (if not only) mechanism for the very brightest AGN. Major mergers remain the most commonly accepted method for triggering high-luminosity AGN, though there is little evidence they are also responsible for low-luminosity AGN.

Galaxies in clusters have a high chance of merging and have frequent interactions. However, the galaxies in the centre of a cluster are gas-poor. The velocity dispersion in the centre of a cluster is also too high for major mergers to occur (Binney & Tremaine 2008; Martini et al. 2007). In less dense regions and in isolated galaxies, the galaxies are more gas-rich but the number density is lower, making interactions and mergers less likely. An intermediate environment might be in groups where there are neighbour galaxies, where there is still enough cold gas available and the galaxy velocity dispersion is low enough to enable mergers to take place (Arnold et al., 2009). Mergers are likely to be rare in cluster environments.

During the early stages of a merger, tidal interactions cause an increase in star formation and accretion onto the central black hole, though the effect is weak. During the final stages of merging, large inflows of gas will trigger strong starbursts, which can be seen in ULIRGS and sub-millimetre galaxies. The inflows also feed the black hole, but the central black hole is obscured in the optical due to dust. Finally the gas (and dust) is consumed by the black hole and starbursts or blown out of the system by AGN feedback. This causes the quasar to become visible in the optical leaving a red sequence host and bright quasar (Hopkins et al., 2008).

Merger rates increase with redshift, which has been suggested to explain some of the increase in quasar activity and the activity peak at z$\sim$2-3 (Carlberg, 1990) but not all (Kauffmann & Haehnelt, 2000). The decrease of activity towards lower redshifts is also likely to be affected by a decrease in the fuel available to the black holes. It is believed that the accretion efficiency changes with redshift so black holes accrete at slower rates at later times (Kauffmann & Haehnelt, 2000).

As the shape of the merging galaxies is distorted by the merger, if mergers are a dominant fuelling mechanism, it is expected that the host of the AGN would show evidence of these distortions. Some authors find evidence for tidal interactions and mergers (e.g. Bahcall et al., 1997; Hutchings et al., 2003; Bennert et al., 2008) while others suggest the hosts of AGN are indistinguishable from those of isolated elliptical galaxies which are not interacting (e.g. Dunlop et al., 2003; Cisternas et al., 2011). Most AGN hosts (>85%) show no evidence of strong distortions and there is no significant difference in the number of galaxies with distortion features between active and inactive galaxies (Dunlop et al., 2003; Cisternas et al., 2011). This suggests active galaxies are involved in mergers at the same rate as inactive galaxies. In the redshift range $0.3 < z < 1$, Cisternas et al. (2011) found over 50% of the AGN hosts were disk dominated suggesting the AGN was formed by a triggering mechanism which would not destroy the disk as a major merger would.

A minor merger consists of a galaxy and a satellite or dwarf galaxy with a mass ratio of 10:1 or greater, and may result in less luminous AGN than those produced in major mergers. These are likely to be more common than major mergers. In fact, more galaxies are likely to have accrued a large percentage of their mass through minor mergers of discrete subunits (e.g Ostriker & Tremaine, 1975), compared to 20% at most which have been through a major merger (e.g. Hernquist & Mihos, 1995). Minor mergers can "drive structural evolution in disks without completely destroying them" (Hernquist & Mihos, 1995, and references therein). The disk may be warped or heated and this may be the origin for the "thick" disk (e.g. Walker et al., 1996). Minor mergers can also drive material into the centre of the host galaxies, fuelling an AGN.

1.6.2 Interactions and Galaxy Harassment

Galaxy harassment caused by close interactions of galaxies can create dynamical instabilities in the galaxy and rapidly channel gas into the centre of a low luminosity host. During the first encounter, a bar instability is formed, stronger than that induced by the cluster's tidal field alone. Within a few billion years, 90% of the gas in a galaxy can be driven into the central 500 pc (Lake et al., 1999).

The strongest encounters do not necessarily occur in the centre of the cluster (Lake et al. 1998). The impact of the galaxy harassment depends on the square of the masses of the largest galaxies encountered. If galaxies are tidally limited, the more massive galaxies will lie on the edges of the cluster. Also, the velocity of the galaxy decreases in the outer regions of a cluster, which makes the encounter stronger (Lake et al. 1998). Alonso et al. (2007) determine that, in an interaction, the luminosity of the paired galaxy may be important in determining the AGN activity.

The infall of field galaxies peaks between redshifts of 0.3 and 0.5 (Kauffmann, 1995) so if harassment is the cause of nuclear activity in quasars in sub-L* galaxies, the frequency of AGN in clusters should also peak in this redshift range in clusters, which is shown in the Butcher-Oemler effect (Lake et al. 1998). The Butcher-Oemler effect (Butcher & Oemler, 1978) suggests that the cluster core of rich clusters at intermediate redshifts ($z \sim 0.3 - 0.4$) will contain more blue galaxies than lower redshift clusters.

1.6.3 Hot gas

Another approach is to consider that AGN could be formed during the host galaxy formation and the main source of fuel is the interstellar medium formed as the galaxy collapses (Nulsen & Fabian, 2000). The first galaxies collapse, which forms a hot gas and then the first quasars form shortly after. During the collapse, the radiative cooling is quicker than the shock heating so the gas is cooled quickly. In the collapse of large systems, some gas can form a hot atmosphere after the collapse. As the cooling time is less than the time needed for the collapse, the hot gas will start to cool and forms a cooling flow (Fabian, 1994), from which the black hole accretes hot gas. The black hole growth is determined by the temperature of the gas and the Mach number of the cooling flow.

This hot gas is depleted as time goes on and the accretion rate will drop to where the efficiency of accretion plummets causing the quasar to shut off. The depletion of hot gas does not, however, explain the lack of luminous AGN at the current epoch as there are nearby ellipticals which have a supply of accretable hot gas but have low accretion luminosities. This could be due to the accretion flow becoming advection-dominated and therefore, having a low efficiency rate (Reynolds et al., 1996; Di Matteo & Fabian, 1997).

This model, however, fails to account for the number of luminous AGN at $z \sim 2$ and earlier. This model over-predicts the number of quasars with respect to the optical luminosity function but is consistent with models from the X-ray background (Nulsen & Fabian 2000; Somerville et al. 2008).

1.6.4 Bars

Stellar bars can be seen in abundance in spiral galaxies (possibly out to z$\sim$1). They vary in strength, exert a gravitational torque, and alter the mass and angular momentum distribution of material in the galaxies. 30% of spiral galaxies have strong bars (in the optical), a figure which increases to 50%, if weak bars are included. Bars represent a strong non-axisymmetric distortion of the galaxy mass distribution (Binney & Tremaine, 2008). They contain prominent dust lines on the leading edge of the bar so are more prominent in near IR images.

Mulchaey & Regan (1997) found no excess of bars in Seyfert galaxies, while Jenkins et al. (2011) found almost 80% of Seyfert Type 2s are barred spirals. Not all barred spirals show evidence of AGN but due to the lifetime of AGN activity, this would not be expected. Also not all AGN in spirals have bars.

In strong bars, the net gas-flow rate is typically <1 kms^{-1}, which though small, is enough to transport most of the gas in a galaxy into the centre within a galaxy's lifetime (Binney & Tremaine, 2008). Once the gas has been transported to the centre, it gathers in circular orbits and creates nuclear rings, which have typical radii of a few hundred pc. These rings are possible reservoirs for the accretion disks, though another mechanism is then needed to move the gas onto the accretion disk region.

1.6.5 Choosing between fuelling mechanisms

Studying the properties of the host galaxies and environment can determine the likelihood of each fuelling mechanism occurring. A major merger will create a luminous AGN in an elliptical galaxy. There may be evidence of tidal features such as shells and tails in the host (Bennert et al., 2008) (though not always as these features may decay, Schawinski et al. 2010). The luminous AGN are likely to lie in areas with a low velocity dispersion and an intermediate density (Arnold et al. 2009). Major mergers are likely to be the cause of bright AGN and be dominant at higher redshifts.

Minor mergers and galaxy harassment cause instabilities in the host galaxy and the size of the interaction depends on the mass of the largest galaxy. Harassment is also likely to create ellipticals (Lake et al., 1998) (though this will depend on the strength of the harassment) while in minor mergers, the disk can survive (Hernquist & Mihos, 1995). Secular processes such as bar instability are likely to be more dominant in the local universe and create lower luminosity AGN.

Different mechanisms may be dominant at different times and in different environments.

1.7 Quasar formation

To create an observed luminosity of $10^{12}\mathrm{L}_\odot$, the quasars must have an accretion rate of $2\mathrm{M}_\odot\ \mathrm{yr}^{-1}$. (This assumes the standard efficiency rate of $\epsilon \sim 0.1$.)

The highest redshift quasar found is $z = 7.085$, which has a luminosity of $6.3 \times 10^{13}\mathrm{L}_\odot$ (Mortlock et al., 2011). The spectrum for this quasar is similar to lower redshift quasars of the same luminosity. This quasar is estimated to have a black hole of mass $2 \times 10^{9}\mathrm{M}_\odot$, which will place strong limitations on black hole formation and accretion mechanisms, as formation mechanisms must account for a 2×10^9 $M_\odot$ black hole only 0.77 Gyr after the Big Bang. The quasar formation mechanism for small black holes ($M \sim 10^5 M_\odot$) may be different to that for more massive AGN (Haehnelt et al., 1998), though it is currently not possible to detect black holes with M< $10^6 M_\odot$.

In the early universe ($z > 6$), the galaxy systems were rich with cold gas, had rotation-dominated dynamics, and contain a small "seed" central black hole. They were clumpier and more turbulent than present day blue galaxies. The size of the dark matter halo in which optical quasars are found ($M_{halo} \sim 3 \times 10^{12} M_\odot$) remains constant with redshift. At least some black holes formed early on (Silk & Rees, 1998). Shen (2009) modelled major mergers and predicted most of the black holes with M> $10^{8.5} M_\odot$ will be in place by $z = 1$ and 50% in place by $z = 2$. (For lower mass black holes, the processes are likely to be secular and assembled more recently.)

1.8 Large Scale Structures

Large Scale Structure (LSS) is the product of the mass distribution of the early Universe, observed today as filaments and clumpy structures connected by galaxy clusters (York et al., 2000; Colless et al., 2001) and in place at high redshifts (Bond et al., 2010). Structures have been found at a range of redshifts (e.g. $z = 0.55$, Tanaka et al. (2009); $z = 0.73$, Guzzo et al. (2007); $z = 0.985$, Le Fevre et al. (1994), to name a few) and the evolution with redshift has been studied (Choi et al., 2010).

Clusters lie along filaments or mostly commonly lie on the nodes of structures with prominent filamentary structures around them (Bond et al., 1996; Springel et al., 2005). The filaments provide pathways in which to accrete matter onto the galaxy clusters (e.g. Tanaka et al., 2007).

Superclusters (for example, the Sloan Great Wall, the Shapley Supercluster and the Sculptor Supercluster) are comprised of a number of clusters or groups in a network of filaments on the scale of 10-100 Mpc (Kocevski et al., 2009). These were the sites for early star formation and formed earlier than smaller structures. In rich superclusters, the core of the structure will contain more early type red galaxies and richer groups than the outskirts of the supercluster, and contain a larger fraction of X-ray clusters. These differ from poor superclusters by the presence of a high density core. Galaxies in rich clusters have lower star formation rates than galaxies in poor clusters (Porter & Raychaudhury, 2005, 2007; Einasto et al., 2008). The environment of a supercluster affects properties of the galaxy groups and clusters located within it.

The largest known structures in the Universe are Large Quasar Groups (LQG) which can cover 50-200h^{-1} Mpc and contain between 4 and 25 quasars (e.g. Crampton et al., 1987; Clowes & Campusano, 1991, 1994). These clusters of quasars exist at high redshifts, presumably trace the mass distribution, and are potentially the precursors of the large structures seen at the present epoch, such as superclusters (Komberg & Lukash, 1994). There are $\sim$40 published examples of LQGs.

1.9 Environments

At radii between 25 kpc and 1 Mpc from the galaxy centre, quasars are found in higher density regions than L* galaxies, with the overdensity being greatest closest to the quasar (Serber et al., 2006). Observational studies have found a small-scale excess at scales below $\sim$100 kpc h^{-1} (Hennawi et al., 2006; Myers et al., 2007), and are supported by simulations (Degraf et al., 2011).

On scales of between 1 and 10 Mpc, AGN and quasars have been suggested to lie in environments similar to that of L* galaxies (e.g. Smith et al., 1995; Croom & Shanks, 1999). On scales of 10 Mpc and greater, quasars are more strongly clustered than galaxies but less than rich clusters (Serber et al., 2006, and references within). In nearby quasars, underdensities of bright galaxies in the environments around quasars were found at a few Mpc (Lietzen et al. 2009). Hutchings et al. (1993) and Tanaka et al. (2001) found an excess of faint red galaxies around a quasar at $z\sim$1.1, extending for $\sim 20h_{50}^{-1}$ Mpc.

There are different conclusions as to whether AGN and quasars lie in dense regions and are therefore, affected by their environment. For example, Coldwell & Lambas (2006) suggest the galaxy number density around AGN and quasars is similar to that around typical galaxies so there is no relation between the AGN activity and its environment. Miller et al. (2003) also find no difference in the local density of AGN and field galaxies. However, other authors (e.g. Serber et al., 2006) have found an increase in the local density around quasars greater than that around typical L* galaxies. This discrepancy could be explained by the fact that luminous AGN do avoid high density areas but low-luminosity AGN do not (Kauffmann et al. 2004; Kocevski et al. 2009; Lietzen et al. 2009). AGN are preferentially located 1-2 Mpc from the centres of the clusters (Johnson et al., 2003; Söchting et al., 2004). This excess may increase with redshift.

Dim AGN in the redshift range $0.3 < z < 0.8$ have the same clustering properties as typical local galaxies (Shirasaki et al., 2009). Dim AGN in the range $0.8 < z < 1.5$ show evidence of lying in denser environments than typical galaxies, as do bright AGN in the redshift range $1.5 < z < 1.8$, which suggests a redshift evolution in the density preferred by both bright and dim AGN (Strand et al. 2008). Assuming AGN are the result of major mergers, the assembly of large systems will occur more frequently in denser areas so the bright AGN should be seen in denser environments. However, the mass assembly of large systems stops at an earlier time than small systems and small scale assembly continues so bright AGN can be produced via low-mass assembly at a later epoch and lie in sparser regions (Shirasaki et al. 2009).

At low redshifts, many quasars are on the edges of rich clusters (Oemler et al., 1972; Green & Yee, 1984; Yee, 1987; Söchting et al., 2002), though some lie in the centres of clusters (Schneider et al., 1992; Yee, 1990). The AGN fraction may also be higher in clusters with low velocity dispersions as mergers become more likely (Gavazzi et al. 2011).

The general consensus is that galaxies in denser environment are less likely to host an AGN (Kauffmann et al. 2004; von der Linden et al. 2010; Gavazzi et al. 2011).

1.10 Current Standing and Motivation

Currently, the roles of mergers, harassment and secular process are still in debate. However, it is believed that different mechanisms dominate at different times.

Some authors have found AGN in overdense regions (e.g., Serber et al. 2006; Georgakakis et al. 2007), while others found no difference between the environments of AGN and fields galaxies (e.g., Miller et al. 2003; Waskett et al. 2005; Martini et al. 2007), or that AGN avoid overdensities (e.g., Popesso & Biviano 2006). This discrepancy could be explained by the fact that luminous AGN do avoid high density areas but low-luminosity AGN do not (Kauffmann et al. 2004). This result also depends on the wavelength used to observe the AGN as different types of AGN may reside in different environments (Lietzen et al. 2011). For example, radio AGN are strongly clustered and reside in high density regions, while AGN detected in the IR are weakly clustered (Hickox et al. 2009).

However, a general consensus is developing that AGN prefer intermediate density regions, such as galaxy groups (e.g. Waskett et al. 2005; Gilmour et al. 2007; Silverman et al. 2009). In this environment, galaxy mergers are likely to occur. Mergers are more frequent in groups than clusters, due to the lower velocity dispersion and high density (Popesso & Biviano 2006; Lin et al. 2010). Mergers are thought to create high luminosity quasars, as a merger can quickly drive large amounts of material into the centre of the galaxy. Mergers are also likely to dominate high mass systems, $M_{gal} > 10^{11}$ $M_{\odot}$ (Hopkins et al. 2008). However, Cisternas et al. (2011) found over 50% of the AGN hosts were disk dominated in the redshift range $0.3 < z < 1$. This suggests major mergers can not be a dominant mechanism as a major merger would destroy the disk.

Galaxy harassment can create lower luminosity AGN, as harassment will drive less gas into the galaxy centre and onto the black hole. Galaxy harassment is also likely to occur where the relative velocity of the encounters is decreased, but also potentially in higher density environments (Silverman et al. 2009). Harassment can also occur in the centre of a cluster where the cluster's tidal field will have a strong effect on the galaxy.

There is also still much debate as to whether there is any evolution with redshift (Fanidakis et al. 2010) The merger rate is higher at higher redshifts ($z > 2$), as at lower redshifts, the gas supply in the galaxies has been depleted. However, Williams et al. (2011) found few additional mergers occurring at $z = 1 - 2$ than at lower redshifts. Galaxy harassment has been proposed for lower redshifts to account for the number of lower-luminosity AGN at low redshifts (Silverman et al. 2009). While secular processes are most likely to be dominant in the present universe and in small galaxies (Hopkins et al. 2008).

Strand et al. (2008) found that brighter quasars lay in denser environments than dimmer quasars on small scales, and Hasinger et al. (2005) found a peak in the X-ray AGN luminosity function at $z \sim 0.7$. Bright AGN show a stronger evolution with redshift, with a space density peak at $z \sim 2$ as opposed to fainter AGN, which show less evolution with redshift and have a peak in space density at lower redshifts, $z < 1$ (Hasinger et al. 2005; Fanidakis et al. 2010). However, others (e.g., Adelberger & Steidel 2005) found no evidence of luminosity dependence in the clustering properties of AGN and galaxies.

However, the impact of environment on AGN and quasars and their evolution with redshift and luminosity are still controversial subjects. The aim of this work is to study the large scale environment over a large redshift range and study any potential evolution as well as any change in environment with luminosity.

1.11 Outline of the Thesis

Chapter 2 describes the data samples and surveys used in this thesis, as well as the methods created to analyse the data.

Chapter 3 studies the proximity of quasars with respect to galaxy clusters and any evolution of the distance between a quasar and the closest cluster with redshift. This chapter also contains a study of the distance between a quasar and the closest cluster with respect to other cluster parameters such as the cluster richness, and the orientation of the quasar with respect to the cluster major axis.

In Chapter 4, the evolution of the position of the quasar as a function of the quasar luminosity is studied. Again, the orientation of the quasars with respect to the cluster major axes is studied, along with the influence of cluster richness on the quasar luminosity. The luminosities of quasars lying within a cluster have been discussed.

Chapter 5 describes the properties of a set of spectra from star-forming galaxies, red galaxies and AGN. This chapter uses spectra selected by Haberzettl et al. (2009) and observed by Luis Campusano and Ilona Söchting. The data reduction is described, the objects have been classified and star formation rates have been calculated and discussed.

Using the AGN and star-forming galaxies classified in Chapter 5, the environments of AGN have been studied with respect to the star forming galaxies in Chapter 6.

Chapter 7 contains the study of a set of quasars with ultra-strong UV FeII emission within Large Quasar Groups. The spectra for these quasars was taken by Lutz Haberzettl on the Hectospec instrument.

Chapter 8 contains the summary and an outline of future work.

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