Host galaxies and environment of active galactic nuclei : a study of the XMM large scale structure survey

Tasse, C.

CHAPTER 7

Summary and discussion

As discussed in the introduction of this thesis, unified schemes are very successful in explaining properties of many classes of AGN. However, many authors have argued that it does not properly describe the low-power radio-loud AGN. These AGN often lack the observed features of the unified scheme: they do not show evidence for luminous emission lines (Jackson & Rawlings 1997), infrared emission from dusty torus (Whysong & Antonucci 2004; Ogle et al. 2006) and accretion related X-ray emission (Hardcastle et al. 2006; Evans et al. 2006). It has been proposed that the super-massive black hole in these systems may be accreting with a radiatively inefficient accretion ("Radio mode"), as opposed to the emission line selected AGN, which are recognised as being associated with radiatively efficient accretion ("Quasar mode", Heckman et al. 2004; Best et al. 2005). Interestingly, Best et al. (2005) have shown that AGN as selected using criteria on emission line luminosity or on radio power are statistically independent, suggesting these classes of AGN are triggered by different mechanisms. These two accretion modes might be driven by the temperature of the gas reaching the super massive black hole (see Hardcastle et al. 2007, for a discussion). In this framework, the accretion of cold gas produces a radiatively efficient accretion disk, while hot gas accretion drive an advective accretion, having low radiative efficiency. It has also been proposed that the type of triggering process determines the temperature of the gas reaching the black hole: "wet" galaxy mergers bring the cold gas to the central super massive black hole, thereby triggering quasar mode AGN, while the intergalactic medium (IGM) hot gas cooling triggers a low efficiency hot gas accretion (radio mode).

7.1 Summary

In order to test this scheme, we have studied in this thesis the properties of AGN populations in the XMM-LSS field. Specifically, we have selected two samples of AGN based on (i) radio luminosity and (ii) X-ray luminosity. To do this, we have carried out a deep low-frequency radio survey with the Very Large Array at 74 and 325 MHz, covering 132 and 15.3 degree^2 , leading to the detection of 1500 radio sources. To increase our sample size, we have also observed the XMM-LSS field with the Giant Meterwave Radio Telescope at 240 and 610 MHz. From our radio sources catalog and from the X-ray catalogs of Pacaud et al. (2006), we have identified the radio and point-like X-ray sources with their optical and infrared counterparts in the CFHTLS-W1 and SWIRE surveys. Using the ZPEG stellar synthesis code, we have estimated stellar masses, star formation rates, and redshifts for the normal galaxies, and for the AGN. In order to obtain samples of AGN having reliable photometric redshifts we have developed a method for rejecting the broad line Type-1 AGN. In addition, we have constructed an overdensity parameter based on the photometric redshifts probability function, that gives the significance of the density around a galaxy.

We have classified the radio and X-ray selected AGN in three classes based on their generic properties. The results are as follows:

(I) **Radio selected** AGN with $M \gtrsim 10^{10.5-10.8}$ $M_{\odot}$: The fraction, f_R, of radio-loud AGN is a strong function of the galaxies stellar mass following the $f_R \propto M^{2.5}$ relationship as found at $z \lesssim 0.3$ (Best et al. 2005). These AGN do not show signs of infrared excess. They are preferentially found in poor cluster environment, while no signs of small 75 kpc scale overdensity is detected around them.

(II) **Radio selected** AGN with $M \lesssim 10^{10.5-10.8}$ $M_{\odot}$: The fraction of radio-loud AGN has a flatter $f_R - M$ relation as compared to the $M \gtrsim 10^{10.5-10.8}$ $M_{\odot}$ galaxies. These galaxies show a hot infrared excess at wavelength as short as 3.6 μm (observer frame). Their environment is very different from the environment of the higher stellar masses objects, in that they lie in large scale underdensities, while their small 75 kpc scale overdensity is higher.

(III) **X-ray selected** AGN: The fraction of X-ray selected AGN with $L_{[2-10]\mathrm{keV}} > 10^{43}$ erg.s^{-1} is a strong function of the stellar mass. The slope of that function is in good agreement with the same relation for the emission line selected AGN, while it disagrees with the fraction-mass relation for the radio selected AGN. Over all the probed stellar mass range X-ray selected AGN show an infrared excess in the near infrared. These AGN are preferentially found in environment underdense on large scales.

7.2 Discussion

We argue in this section that the properties of AGN in the XMM-LSS field support the picture in which there are indeed two very distinct populations of AGN (“Quasar mode” versus “Radio mode”, Best et al. 2005; Hardcastle et al. 2007). We further discuss the relations that might link the triggering processes to these accretion modes.

Our radio selected AGN (I) with $M \gtrsim 10^{10.5-11}$ $M_{\odot}$ seem to be radio mode AGN, as no hot infrared emission is observed for these objects. Best et al. (2005) has argued that the fraction f_R of radio-loud galaxies versus their stellar mass relation ($f_R \propto M^{2.5}$) is generated by the dependency of the IGM gas cooling rate on the stellar mass (Mathews & Brighenti 2003). The mass fraction relation found for the radio selected AGN (I) in our sample agrees with $f_R \propto M^{2.5}$ found at $z \lesssim 0.3$ in the SDSS (Best et al. 2005). These AGN that are in their radio mode, are not sensitive to their local (75 kpc) density, but their large (450 kpc) scale environments are denser than the average. In other words, in such stellar mass range, increasing the density of the surrounding environment on large scales increases the probability that a galaxy is a radio-loud AGN. Altogether, this supports the picture in which their AGN activity is triggered by the IGM hot gas cooling in their atmosphere.

Interestingly, populations (II) and (III) have similar internal and environmental properties, while they are both very different from population (I). The slope of their AGN fraction versus mass relation is similar to the one for emission line selected AGN that are recognised as being AGN in their highly accreting quasar mode (Heckman et al. 2004; Best et al. 2005; Heckman & Kauffmann 2006). In addition, both the (II) and (III) population show infrared emission from hot dust at 3.6 μm, indicating that black holes are accreting in a radiatively efficient quasar mode. Furthermore, their environments are similar: in a given stellar mass bin, they are found to be preferentially located in large 450 kpc scale underdense environment, with their small 75 kpc scale overdensity being higher on average, which suggests that these populations are indeed the same. Gas-rich galaxy mergers and interaction have often been proposed as mechanisms for triggering the black hole activity (Springel et al. 2005), while this process has been suggested to occur more frequently in underdense environment (Gómez et al. 2003; Best 2004). It may therefore be that the activity of those AGN is triggered by the galaxy mergers and interactions that feed the black hole with cold gas. Alternatively the AGN may be fuelled by cold gas that is infalling from the IGM and also forming stars in the host galaxy. In order to have such cold gas infall, the gas cooling time must be lower than the dynamical infall time, and that is more likely in underdense regions: in the context of large scale structure formation, overdensity correspond the shock-heated, high temperature IGM, while the temperature of the IGM gas in underdense regions is lower.

Altogether, our results are consistent with the picture in which there are two types of accretion, with the first being radiatively efficient "Quasar mode" and the second being radiatively inefficient "Radio mode" (Best et al. 2005; Heckman & Kauffmann 2006; Hardcastle et al. 2007). Our most important result is that those two classes of AGN seem to lie in very different $\sim$ 450 kpc scale environments, suggesting that the nature of the triggering mechanisms might be connected to the rise of these two accretion modes. Hardcastle et al. (2007) discussed a physical picture in which the accretion mode is determined by the temperature of the gas reaching the black hole, with that temperature being connected with both the nature of the triggering process and the environment. In such scenario, for the radio mode accretion, the IGM hot gas cools and reaches the black hole at too high temperature to form a radiatively efficient accretion disk, so it rather accretes spherically. In contrast, the gas-rich galaxy mergers or the cold IGM gas in underdense regions might preferentially bring cold gas to the central black hole, giving rise to a disk-like radiatively efficient accretion (quasar mode).

In this picture these competing triggering processes depend on the large scale environment. It might be that there is quite a direct link between the large scale structure formation and the observed evolution of the AGN luminosity functions.

References

Best, P. N. 2004, MNRAS, 351, 70

Best, P. N., Kauffmann, G., Heckman, T. M., et al. 2005, MNRAS, 362, 25

Evans, D. A., Worrall, D. M., Hardcastle, M. J., Kraft, R. P., & Birkinshaw, M. 2006, ApJ, 642, 96

Gómez, P. L., Nichol, R. C., Miller, C. J., et al. 2003, ApJ, 584, 210

Hardcastle, M. J., Evans, D. A., & Croston, J. H. 2006, MNRAS, 370, 1893

Hardcastle, M. J., Evans, D. A., & Croston, J. H. 2007, MNRAS, 376, 1849

Heckman, T. M. & Kauffmann, G. 2006, New Astronomy Review, 50, 677

Heckman, T. M., Kauffmann, G., Brinchmann, J., et al. 2004, ApJ, 613, 109

Jackson, N. & Rawlings, S. 1997, MNRAS, 286, 241

Mathews, W. G. & Brighenti, F. 2003, ARA&A, 41, 191

Ogle, P., Whysong, D., & Antonucci, R. 2006, ApJ, 647, 161

Pacaud, F., Pierre, M., Refregier, A., et al. 2006, MNRAS, 372, 578

Springel, V., Di Matteo, T., & Hernquist, L. 2005, ApJ, 620, L79

Whysong, D. & Antonucci, R. 2004, ApJ, 602, 116