Circumnuclear Activity

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Abstract. Clues to the question of the origin of nuclear activity are provided by the response of the host galaxy and the surrounding intergalactic medium to the AGN power output. The nature of the rich variety of circumnuclear activity is discussed and particular emphasis is placed on attempts to understand these processes in the active galaxies, both quasars and powerful radio galaxies, which are being discovered at very high redshift. Although extreme in character, these objects give us one of the few direct views we have of galaxies and their formation processes at an early epoch.

1 Introduction

The phenomenon that we call 'nuclear activity' is most probably the consequence of events or processes which feed material into a high density region in the centre of a galaxy. The rapid evolution of this material, through various dissipative interactions, results in bursts of star formation, the formation of a massive collapsed object or both. The feeding of the nucleus can be the result of relatively quiescent gas flows such as those seen in bars — much discussed in this symposium — or catastrophic events associated with galaxy interactions or mergers. One of the key questions in the science of galaxies is the frequency of occurrence of currently unfed collapsed objects and the implications this carries for the evolution of the system.

The various interactions between an active nucleus and its host galaxy produce a rich variety of phenomena from which much can be learned about galactic structure and evolution. In the nearby Seyfert galaxies the axial symmetry of the AGN which produces the beautiful 'ionization cones' seen in highly excited emission lines appears to be independent of the symmetry of the generally spiral host galaxy (see particularly the contribution by Tsvetanov). The details of the relationship between the star formation and AGN processes can be well studied in these objects where high resolution imaging from the ground and from HST shows an apparently close coupling between circumnuclear rings and the nucleus. In the high redshift quasars and powerful radio galaxies — which we believe to host very luminous but partly hidden quasars — the AGN illuminates material within a huge volume. The evidence for this appears both in the very extended emission line regions seen around the objects and in the absence of absorption lines from low ionization species — notably Lyα — close to the emission line redshift of quasars: the 'proximity effect'. When we learn to read the signs written by ionization, fluorescence and scattering, we will witness aspects of the galaxy formation process which would be very hard or impossible to see in objects without an AGN at this early epoch.

From the optical observer's perspective, it appears that the dominant influence of the AGN on its host galaxy and extragalactic environment is via the photon radiation field. These photons ionize surrounding gas and scatter from dust and electrons. In the radio loud sources, however, there is much evidence for the interactions produced by the radio jets which extend up to tens or hundreds of kiloparsecs from the nucleus. The detailed physics of jet/cloud collisions is complex and difficult to unravel but may tell us much about the properties of the jets which feed the radio lobes and also something about the material on large spatial scales surrounding galaxies.

In this contribution, I want to place my emphasis on the prospects for the study of galaxies at the very highest redshifts. Here, the radio galaxies are currently our primary probes of the nature of galaxies at early epochs. This is not so much by design but is rather the result of the highly successful search techniques for the most distant objects based on radio properties (McCarthy 1993, Röttgering 1993). Indeed, one of our most important tasks is to recognise those aspects of the observed properties which are a direct result of the presence of a powerful AGN and to separate these form the stellar structures which may teach us about the formation of 'normal', or at least less extreme, galaxies.

Although I profess an interest in high redshifts, the diagnostic tools which help us have been developed by application to sources much closer-by. Consequently the Seyfert ionization cones, the radio jet/cloud interactions, the extended emission line regions around low redshift radio galaxies; indeed, all the trappings of extranuclear activity, will form part of the story which culminates at an epoch which is tantalisingly close to that where galaxies must be forming. I will start with a brief survey of the range of phenomena we observe around AGN and then go on to discuss some aspects in a little more detail.

2 The Phenomena

A substantial foundation for the subject was laid during the pioneering optical spectrophotometry of Seyfert nuclei carried out with the then-new electronic spectrum scanners principally by Osterbrock and his students and collaborators during the 70's. These early scanners were one-dimensional devices and so produced an integrated spectrum of the nuclear region of the galaxies which, for the nearby Seyferts, generally corresponds to the inner 100 pc or so. The slightly later advent of the two-dimensional detectors (Boksenberg's Image Photon Counting System (IPCS) and CCDs) led to the discovery that in some objects, most notably the radio galaxies, the high ionization emission lines which characterised an AGN were not necessarily restricted to the very nucleus but could be seen up to 100 kpc or so from the galaxy.

The astrophysical study of these extended emission line regions (EELR) led to the notion that they were excited by the AGN — most probably by the

EUV radiation field. This straightforward interpretation did, however, lead to a problem in some objects which became known as the 'photon deficit' (Robinson 1989). Using any reasonable extrapolation of the nuclear optical nonstellar continuum into the ionizing ultraviolet, there appeared to be insufficient photons to account for the line luminosity and the ionization state of the extended gas. There were two favoured explanations for the deficit problem (see Fig. 1). In the first, it was proposed that the continuum extrapolation could be wrong: instead of a power law extending into the Lyman continuum, there may be a hot ($1 - 2\times10^5$ K) 'thermal' ionizing spectrum which was essentially invisible in the optical. Distinguishing between power-law and hot black body ionizing spectra using the standard optical emission line plasma diagnostic techniques is not straightforward (Robinson et al. 1987) and it remains likely that 'EUV bumps' do play some role in exciting EELR. It was soon realised, however, that the observer and the extended ionized gas did not necessarily share the same view of the AGN. The resulting concept of an anisotropic radiation field has been remarkably successful, allowing us to understand a variety of AGN properties. In conjunction with a number of related contemporary studies it has led to the unification of apparently different classes of object based on the predominant importance of the viewing direction.

The recognition of the radiation anisotropy allowed the inference of nuclear properties even in objects whose AGN were not directly visible because of obscuration. Perhaps surprisingly, the diagnostic tools based on the optical emission line spectra — mostly ratios of forbidden and subordinate recombination lines — indicated some remarkably uniform properties for the EELR: both within an object and amongst different objects. Robinson et al. (1987, hereafter RBFT87) showed that the ionizing spectra could be characterised by a mean ionizing photon energy of 30 – 40 eV with rather little dispersion. Similarly, there could be little variation — within factors of two or three — in the chemical composition of the EELR in the sample of relatively low redshift radio galaxies studied. The dominant parameter representing the spread of spectra within the line ratio diagnostic diagrams is, in fact, the ionization parameter — the ratio of ionizing photon to gas density — which represents the degree of geometric dilution of the radiation field. This uniformity suggests to me that the EELR phenomenon, at least in these low redshift objects, is dominated by a single line excitation process, most probably nuclear photoionization. While there is strong evidence in some cases for local, extranuclear sources of ionizing radiation, e.g., in jet/cloud interactions, I do not believe that such processes contribute a very significant fraction of line emission in the global EELR phenomenon. This conclusion may, however, need to be revised at high redshifts where there is more evidence for disturbed kinematics and apparently a closer association between the line emission and the radio structures.

One of the tasks engaging us now is, indeed, the extension of these diagnostic techniques into the ultraviolet where we can use them to study the spectra of high redshift objects observed in the optical from the ground. Because the UV spectra are rich in resonance lines, geometric effects and the presence of dust

Fig. 1. An illustration of the photon deficit problem in AGN. The apparent absence of sufficient nuclear photons to ionize the extended nebulosity can be explained either as a result of radiation anisotropy or a spectrally 'hidden' ionizing source peaking in the EUV.

become important factors in the development of tools. I will discuss some of this work later. The rewards are potentially great since we have the chance to study the properties and composition of gas lying 100 kpc from galaxies at redshifts up to 4 or so.

Another property of the gas which is readily studied from emission line spectroscopy is its kinematic state. If it can be shown to respond predominantly to the gravitation field, the gas provides an ideal tracer which extends to radii far beyond that seen in starlight. Although there are apparently chaotic gas motions in some objects (Baum et al. 1990; Baum et al. 1992), in many there is evidence of relatively quiescent rotational motion (Tadhunter, Fosbury and Quinn 1988; Hes 1995). An object at $z = 3.6$, studied by van Ojik et al. (1995) shows chaotic motion in the vicinity of the radio structure but smooth rotation in the outer parts of its 135 kpc diameter Lyman-α halo.

The idea of hidden sources led to the brilliant use of polarized light as a 'filter' to detect the small fraction of light scattered into our line of sight by dust or electrons close the nuclei of Seyfert 2 galaxies but outside of the regions which obscured our direct view. Antonucci & Miller (1985) were able to extract the broad line Seyfert 1 spectrum from the Seyfert 2 galaxy NGC 1068. Thenceforward, polarization became a powerful tool for unravelling the non-spherically symmetric geometry of AGN. In retrospect, I find it interesting to see how the recognition of polarization produced by scattering has produced such a rich harvest of understanding quite distinct from that arising from the various non-thermal processes which produce polarized light directly.

The discovery of co-axial radio/optical alignments in powerful radio galaxies beyond a redshift of about 0.7 (McCarthy et al. 1987; Chambers, Miley and van Breugel 1987) proved to be a landmark in the understanding of these distant galaxies. It had generally been thought that the measured blue colours were a result of the presence of a significant hot stellar population which might indicate the youth of the galaxy as a whole. The 'alignment effect' as it became known, spawned several explanatory theories including a proposal that the passage of the radio jets through an extended galactic 'atmosphere' would induce star formation which, for a short time ($\leq$ a dynamical timescale) would trace the jet passage with blue light (see McCarthy 1993 for a review and a complete set of references). The production of blue light by inverse Compton scattering within the region occupied by the relativistic electrons producing the radio emission (Daly 1992) was excluded in many cases because, while co-aligned, the optical and radio emission was generally not co-extensive (e.g., di Serego Alighieri, Cimatti and Fosbury 1993; Miley et al. 1992; Longair, Best and Röttgering 1995). Although the alignment effect is seen predominantly at high redshift — largely because of the shift of the observed waveband into the rest-frame ultraviolet, there are low redshift examples, e.g. in 3C 195 at $z = 0.1$ (Cimatti and di Serego Alighieri 1995).

It is important to understand whether the alignment is purely a K-correction effect or whether there are evolutionary factors involved. Answering this question is not as easy as it sounds because of the necessity to observe nearby objects in the ultraviolet. Here the HST, for all its fine resolution capabilities, is still a small telescope. There is also the extreme rarity in the present epoch of radio sources of comparable power to the objects being studied at high redshift. Cygnus A is the obvious example of a local, luminous radio source and its properties, in the context of the unified schemes, have been extensively studied by Tadhunter (1996) and Stockton and Ridgeway (1996). While there is compelling evidence for an anisotropic ionizing radiation field, the hidden AGN is surprisingly underluminous. Alternatively it may be, in this case, that the radio source — because of the high density cluster environment — is *overluminous* and compact for its AGN power.

The growing realisation during this period that the powerful radio galaxies and the radio quasars could be considered the same class of objects differing principally in orientation (Orr and Browne 1982; Barthel 1989) led Tadhunter, Fosbury and di Serego Alighieri (1989) to suggest that the alignment effect may be caused simply by the scattered and fluorescently excited light from the hidden quasar which radiates photons mostly along the radio axis. This idea was already supported by the emission line spectroscopy which showed extended, high ionization lines which could not arise from ordinary stellar-photoionized HII regions but, instead, appeared similar in nature to the EELR seen at lower redshift. The unambiguous test of scattered light is its polarization state. It was at the limit of the capability of the 4m class optical telescopes to demonstrate that the aligned radio galaxies were linearly polarized with an E-vector position angle fully consistent with the scattering hypothesis. Following the first measurements by di Serego Alighieri et al. (1989, see also Scarrott, Rolf and Tadhunter 1990), a significant body of polarization measurements was accumulated (see Cimatti et al. 1993) which showed that the strong polarization appeared when the observed passband moved below the rest-frame 4000Å break where dilution from the red stellar population disappeared. An objection to this interpretation which stood for some while was the apparent absence of scattered broad lines seen in the extended, aligned structures by analogy with the polarized broad line spectra seen in some Seyfert 2 galaxies. While it is true that the 4m telescopes did manage to solve this problem we are now moving into the era of faint object spectropolarimetry with the Keck telescope which is giving a much clearer view of these phenomena. Before moving on to a more detailed discussion of the high redshift phenomena, I should like to dwell for a moment on what has been learned from studies of nearby objects.

3 Ionization Cones

The apparent biconical ionization cones seen most clearly in the Seyfert 2 galaxies will be discussed in detail by others at this symposium. I shall, nonetheless, review some of their properties as they bear on our observations of more distant and more powerful AGN. I will also note that their existence was presaged by much earlier observations of the distinctly different kinematic behaviour of the high- and low-ionization emission lines in long-slit spectra of Seyferts (e.g., in NGC 1365 by Phillips et al. 1983 and Jörsäter, Lindblad and Boksenberg 1984)

The hypothesis that the triangular regions of highly excited gas, with one apex at the galactic nucleus, are the projections on the sky of bi-conical zones of material illuminated and ionized by an equatorially obscured AGN (Fig. 2) appears to be well supported by observation. The sharp edges seen in some objects, notably in NGC 5252 (Tadhunter and Tsvetanov 1989), suggest that the shapes are limited by the radiation field rather than by the matter distribution — at least on scales up to 10 or 20 kpc. In the same object, Prieto & Freudling (1993) showed that there was apparent continuity, both in morphology and velocity, between the ionized and the neutral gas. The location of the source of radiation at the galactic nucleus is supported both by the cone morphology and by the absence of a sufficiently strong ultraviolet continuum within the cone which could represent a local source of ionization — although we must beware of the possible presence of 'spectrally hidden', hot thermal ionizing sources. The fact that many of the cones are apparently one-sided can be explained by the obscuration of the galactic disk. The general absence of clearly delineated cones in the Seyfert 1s is simply a result of projection: we do not recognise the cones when our line-of-sight lies inside them. What actually constitutes the edge of the shadowing body, however, is still not clear when nearby objects are examined in detail (e.g., NGC 4151, Evans et al. 1993; Pedlar et al. 1993; Robinson et al . 1994). The apparent opening angles of the cones can be influenced both by projection — the angle between the cone axis and our los — and by the distribution of material, e.g., a disk with its plane lying within the cone. We do not yet, in my view, have a sufficient sample of appropriately observed Seyferts — both in terms of sample selection and total number — to rule out the hypothesis that all ionization cones have the same intrinsic opening angle (work in progress by Tsvetanov, Fosbury and Tadhunter).

Fig. 2. A cartoon of the broad ionization cone produced by obscuration of an AGN by a thick torus.

Amongst the known Seyfert 2s with detected ionization cones, there is a very close correspondence between the cone axis and the axis of symmetry of the nuclear radio source, especially when the latter is measured on the smallest spatial scales (Wilson and Tsvetanov 1994). This suggests that the collimation mechanisms of the radio plasma and the ionizing radiation are very closely related although the radio jets are clearly narrower than the cones. These authors also note, however, that there is no relation between the cone axis and that of the galactic disk except, perhaps, in late-type spirals where a weak trend could be produced by an observational selection effect. The apparently ubiquitous occurrence of the phenomenon and the coincidence of the radio and cone axes means that, in these studies, we have a wonderful example of what I call the 'shadow puppet' phenomenon: the use of observations on large spatial scales to map physical structures in galactic nuclei which are still well below direct resolution by telescopes. Since it is so important to be able to overlay accurately images at different frequencies, these studies will be greatly aided by the radical improvement in astrometric precision which will result in the near future from the application of the Hipparcos results to the HST Guide Star Catalog.

Even when seen in projection against the disk, the kinematic state of the cone material can usually be distinguished from it by its different ionization state — specifically by measuring the [O III] and the Hα lines respectively. Such studies are valuable for distinguishing between material which partakes of the general galactic rotation or flow within a bar or is in a radial flow, perhaps associated with radio jet plasma or, possibly, part of a concurrent starburst wind. Detailed studies of the gas kinematics in NGC 1365 are interpreted by Hjelm and Lindblad (1996) as an accelerated radial outflow with the velocities decreasing rapidly towards the cone edges. In the case of some powerful radio galaxies, there are velocity components along the radio axis with velocities as high as thousands of km/s which seem very likely to be due to entrainment of material with the radio jet (Tadhunter 1991). Such extreme velocities along the radio axis appear to be found more frequently at high redshift (McCarthy 1993).

In more distant radio galaxies there are, perhaps, no known cases of the well-delineated cones we see in the Seyferts. Is this simply a matter of lower intrinsic spatial resolution or are there differences in the collimating mechanism and/or matter distribution in the radio-loud objects? Amongst the high redshift radio galaxies (HzRG) which demonstrate the 'alignment effect', the rest-frame ultraviolet morphologies certainly do not resemble the Seyfert cones although, at least, the close axial alignment with the radio source is similar. We must remember, however, that the spatial scale of the extensions in the HzRG is about an order of magnitude larger than that in the nearby Seyferts: deep HST images will be important in resolving this issue and may already be doing so in a few cases.

4 Jet/Cloud Interactions

The particle beams which power the large-scale double radio lobes in the radio galaxies propagate through the host galaxy and its local environment. The beams are very efficient at transmitting power from the nucleus and radiate only very little of this to make themselves visible. Occasionally a jet will hit something more substantial than a diffuse interstellar/intergalactic medium and the resulting interaction produces enhanced radiation over a wide band of frequencies. This can tell a captivating story about both the jets and the galactic neighbourhood.

The detailed physics of such interactions is undoubtedly quite complicated (e.g., van Breugel et al. 1985) but one of the first tasks is to establish the influence of any photon beam generated at the base of the jet at the nucleus (Fig. 3). In the absence of any jet bending, the beam will travel along approximately the same path and can have a profound effect on the interaction site. Such photon beams are expected in both FR I and FR II radio sources (see the review by Urry and Padovanni 1995) and, when aimed at the observer, produce the BL Lac or Blazar phenomenon. One might expect to learn about these beams both from the statistics of completely identified samples of radio sources and from their effect on the excitation and ionization of the EELR. What evidence there is suggests that, while the photon density in the beams can be quite high — producing higher ionization parameters along the radio axis than in the diffuse EELR — the total fraction of the AGN luminosity carried by them is small.

Although there is a general tendency for the EELR excitation state to be higher along the radio axis, there are relatively few cases where a current jet/cloud interaction has been clearly recognised. These are presumably the most promising sites to examine for the presence of local sources of ionization associated with shocks but there may be, even here, a significant or even dominant contribution by ionizing photons from the AGN — especially if there is a beamed component. From the cases which have been studied, there appear to be two distinct kinds of behaviour (Clark and Tadhunter 1996). EELR associated with radio lobe hot-spots (e.g., PKS 2250-41, 3C 171, 4C 29.30 and Coma A) show evidence for shock excitation: highly disturbed kinematics and a relatively low ionization state. The EELR associated with the inner knots in the radio jet (e.g., PKS 2152-699 and the inner source in Coma A), in contrast, have a very high ionization state and a somewhat calmer velocity field. It may be that these latter objects are dominated by the effects of the beamed radiation from the AGN, a conclusion which is supported by the presence of a blue, polarized and presumably scattered continuum in PKS 2152-699 (Tadhunter et al. 1987; Tadhunter et al. 1988; di Serego Alighieri et al. 1988; Fosbury et al. 1990). The interaction site in this object radiates over a very wide band of frequencies, from the radio to the X-ray (Fosbury et al. in prep, see Fig. 4), and is in many ways similar in appearance to an AGN. This may be telling us that many of the observed properties of AGN could be due to jet interactions occurring close to the jet source.

Interesting and very nearby examples are the optical filaments along the radio axis of the FR I radio galaxy Centaurus A. It has been proposed that these are ionized by the BL Lac beam from the nucleus (Morganti et al. 1991, 1992). In this case, the required beam luminosity is very similar to that seen

Fig. 3. In addition to the broad ionization cone there may be — in the radio-loud sources — a Doppler boosted photon beam which, initially at least, travels in the same direction as the particle jet which powers the outer radio lobes.

directly in BL Lac itself. It would make Cen A into a 4th magnitude AGN if seen along the beam axis. An alternative explanation for the ionization of the filaments using the EUV cooling radiation from high speed shocks within the gas clouds (Sutherland, Bicknell and Dopita 1993), while attractive for some interactions, seems inappropriate here since there is no evidence from the radio observations of a jet currently propagating close to the excited gas — although the macroturbulent velocities within the filament structures are quite high.

5 Diagnostic Tools

In addition to the measurement of the structures of extended nebulosities which are assumed to be excited by the AGN radiation field, statistical methods can be used to infer the radiation pattern of the nucleus. To achieve this, complete samples of sources are needed which are selected on the basis of an isotropic property. The low-frequency radio emission is generally assumed to be the most reliable and the 3CR and 3CRR catalogues (McCarthy, van Breugel and Kapahi

Fig. 4. A sketch of the jet/cloud interaction in PKS 2152-699. In this case, there is a common axis of apparently photon-induced activity which is traced from the VLBI scale out to at least 100 kpc. This axis is somewhat displaced from the current large-scale radio axis. The outer [O III]-emitting clouds are well outside the radio structure and are presumably photoionized.

1991; Laing, Riley and Longair 1983) are valuable source lists for such work. Barthel (1989) was able to derive approximate parameters for the obscuration and beaming in these radio-loud objects by analysing the relative numbers of objects classified as blazars, quasars and radio galaxies. Considerable work has been done on the radio and X-ray beaming properties of both the FR I and FR II sources (see the review by Padovanni and Urry 1995) and Morganti at al. (1995) have used Monte-Carlo simulations to analyse the radio properties of their 2 Jy subsample in the south.

Such isotropic selection can also be used as a direct test of the unification hypothesis by examining the individual object classes on the basis of a second isotropic property. Jackson and Browne (1990) applied this test to the [O III] line emission of radio galaxies and quasars from the 3C but it failed for the reason, which we now understand, that much of the [O III] emission from these objects comes from a region which is little larger than the broad line region (BLR) and so is obscured in a similar way. This could be shown to be a plausible explanation if the [O III] line emission is significantly polarized in radio galaxies. By noting that the [O II] lines have a much lower critical density for collisional de-excitation, Hes, Barthel & Fosbury (1993) showed that carefully matched subsamples of quasars and radio galaxies, again from 3C, are indistinguishable from their [O II] luminosity.

A dominant characteristic of much of the circumnuclear activity we have been discussing is the notion of gas clouds being excited by an *external* radiation field. The observed properties of such configurations differ markedly from the classical internally stellar-photoionized H II regions, not only for their different ionizing spectra but also in the importance of the detailed geometry of the clouds, the position of the observer with respect to the illuminating source, and the effects of dust. This distinction becomes particularly apparent in the ultraviolet spectrum where several of the dominant lines are resonance transitions. There have been recent attempts, therefore, to develop photoionization models which take explicit account of the geometry and the physical effects of dust.

Optical studies of EELR in low redshift objects show, in general, little evidence for dust extinction. RBFT87 showed — for a sample of homogeneously observed radio galaxies — that, while the nuclear narrow line spectra exhibit small amounts of reddening, the EELR show none. This does not imply, however, that the EELR clouds are dust-free for it can be shown that reddening is a very insensitive diagnostic of dust in externally photoionized clouds. Because of its importance in understanding many aspects of objects at high redshift — both the stellar properties and the polarization of the aligned light — other methods have been developed to detect the presence of dust.

Measurements from the far-infrared to the mm of objects over a range of redshifts (e.g., Chini and Krügel 1994; Dunlop et al. 1994; Serjeant et al. 1995; Ivison 1995) have detected substantial quantities of dust (up to $10^8 M_\odot$). Little is known, however, about the spatial distribution of the dust and it may be associated with the obscuring torus rather than the very extended extranuclear structures. Observations with ISO will be sensitive to thermal radiation from dust over the whole observed redshift range and, hopefully, the temperature distribution will tell us something about the spatial distribution.

A novel and very sensitive test for dust in emission nebulae is based on detecting the depletion of refractory elements from the gas phase onto dust grains. This was proposed by Ferland (1993) in order to understand the observed weakness of the forbidden ionized calcium doublet in the near-infrared spectra of LINERS. Standard photoionization models with solar gas-phase abundances predict the [Ca II]$\lambda\lambda$7291, 7324 lines to be amongst the strongest in the spectrum at the ionization level of these objects. Observations in the appropriate spectral region of a range of extended nebulosities around galaxies, including so-called 'cooling-flows' were made by Donahue and Voit (1993) who failed to detect the line and concluded the presence of dust. Villar-Martín and Binette (1996) have investigated the problem using the photoionization code MAPPINGS (Binette et al. 1993a,b), adapted to include several important aspects of dust physics, namely the effects of scattering on the radiation transfer and the contribution of dust to the thermal and ionization balance of the plasma. They examined in detail several alternative processes which could suppress the calcium lines but concluded that their absence over a certain range of the ionization parameter must imply depletion. Work in progress by Villar-Martín, Fosbury and Binette applies this modelling to observations of some low redshift radio galaxies and Seyferts with EELR.

The recognition of the importance of the rest-frame ultraviolet spectrum for the study of the nature of objects at the highest redshifts has led to studies of line formation in externally ionized clouds with particular emphasis on the geometrical aspects and the effects of dust on the resonance line transfer. This has many exciting applications for the physical study of objects at the intriguing early stages of galaxy formation and evolution. A particular attraction here for the objects with luminous AGN is the illumination of quiescent material at large radial distances which may only be in the very earliest stages of becoming part of a galaxy.

If we accept the unification of the powerful radio galaxies with the radio quasars — a picture which must be correct at some level (Antonucci 1993) — our studies of the HzRG are constrained by the knowledge of the general properties of the ionizing radiation field from the quasars. The obscuration of the quasar due to orientation does, however, leave us with a clear view of the much fainter EELR which is currently being exploited with the HST and large groundbased telescopes. A powerful technique which follows from the acceptance of unification is the use of the 'associated absorption' spectrum of radio quasars to give a complementary view of the extended structures we see in emission in the radio galaxies. This may help us quantify some of the geometrical factors which characterise the matter distribution and can be applied both with absorption lines and dust absorption/scattering.

The particular geometry of the radio galaxies, with the radio axis lying somewhere between the plane of the sky and about 45° to it, implies that we see clouds both from the front (illuminated) face and from the back. This can result in side-to-side asymmetries both in the line spectra and in the scattered light, especially if dust dominates over electron scattering. Such asymmetries should, in principle, give us a measure of orientation in 3-dimensions which can be compared with radio measurements of jet-sidedness and depolarization asymmetry (Laing 1988; Garrington 1988).

Villar-Martín, Binette and Fosbury (1996) have studied the particular case of the C IV/Lyα *vs* C IV/C III] diagnostic diagram which, because of its inclusion of two resonance lines, is particularly sensitive to geometrical effects (Fig. 5). The computed diagrams are compared with a set of observations which has recently been very significantly enlarged by van Ojik's (1995) work on the ultra-steep radio spectrum selected high redshift objects. We find that the observed trends, in particular the large C IV/Lyα ratios, can be satisfactorily explained in almost all cases by the effects of seeing illuminated clouds from behind or in front. The only cases where dust is needed to quench Lyα are the highly obscured sources like F10214+4724 (Elston et al. 1994) and TX0211-122 (van Ojik et al. 1994) which are probably characterised by a more 'closed' geometry than the other radio galaxies. We also address the question of the neutral clouds — which are presumably outside the radiation cones and so do not see the AGN directly — which produce the spatially extended Lyα absorptions seen in objects like 0943-242 (Röttgering et al. 1995). These screens are clearly kinematically distinct from the line emitting clouds and so are presumably spatially separated from them. Such neutral clouds act as very efficient Lyα reflectors, even if they contain dust, and this process may be responsible for part of the extensive Lyα halos seen to enshroud objects like 1243+036, $z = 3.57$ (van Ojik et al. 1995). Such neutral reflectors could be recognised by the absence of other optical/UV emission lines and it is important to point out that pure Lyα emitters do not necessarily signify star-forming regions.

This particular diagnostic diagram is useful for objects observed from the ground with redshifts greater than about two. Similar tools need to be developed for the intermediate redshift sources.

The production of polarized light in the Seyferts and the radio galaxies by scattering of anisotropically emitted radiation from the AGN has led to an extension of the concept of a 'reflection nebula' to super-galactic scales. The quantitative understanding of these phenomena is hindered, particularly in the case of the HzRG, by the faintness of the sources, the complexity of the geometric structure and, not least, by our ignorance of the precise nature of the scatterers. Assuming the close resemblance of dust found at 100 kpc from a radio galaxy at a redshift of 4 to dust in the Solar neighbourhood today is a leap of faith of gigantic proportions. Nonetheless, models built on the basis of this assumption are quite successful in explaining at least the gross features of the observations (Manzini and di Serego Alighieri 1996). A purely empirical diagnosis of dust or electron scattering in any particular case is rather difficult. Thomson scattering by hot electrons can be distinguished by its thermal broadening of any scattered lines. Using the wavelength dependence of polarization can, however, be misleading because of the presence of one or more unpolarized diluting sources, possibly with different spectra. The effects of a complex geometry on the scattered spectrum and polarization can make it very hard to reach the underlying physical processes. I like to use the analogy of the twilight sky on Earth. This is dominated by Rayleigh scattering from molecules in the atmosphere and the process has a well understood wavelength dependence. The spectacular range of colours produced by a partially illuminated atmosphere viewed along different paths should, however, make us a little cautious when interpreting observations of the colour of galaxy-scale reflection nebulae. An investigation of the observed continua around a rest wavelength of 2200Å will, perhaps give us some direct evidence for the presence of dust and perhaps, even, its nature.

In some cases, particularly close to the AGN — as seen in some Seyfert 2s (e.g., Antonucci, Hurt and Miller 1995) — it is clear that there can be sufficient

Fig. 5. An illustration of the viewing geometry which strongly affects the appearance of the UV emission spectrum of the EELR. The Lyα and C IV resonance lines escape preferentially from the front (illuminated) faces of the clouds. Lyα photons can also be reflected efficiently from neutral clouds which do not see the ionizing radiation from the AGN directly: such reflection may be responsible for part of the extended Lyα haloes seen in some high redshift radio galaxies.

Thomson optical depth to produce diffuse electron scattered radiation. It seems, however, that on the larger scales, scattering by dust is much more plausible due to its considerably higher efficiency per unit mass. The recent discovery of polarized broad lines, similar in width to those seen in quasars, in some HzRG (di Serego Alighieri et al. 1996; Dey and Spinrad 1995) strongly favour dust scattering but does not entirely rule out scattering by a population of cool ($\leq 10^5$K) electrons.

To finish this section, I should like to make a few remarks about the measurement of polarization in these faint sources. Although the polarimetric mode on the Low Resolution Imaging Spectrograph on the W M Keck 10m telescope (LRIS, Oke et al. 1995) is now being used to make superbly high quality measurements, many of the observations which have established the importance of polarimetry for the study of these scattering phenomena have been made with

3–4m-class telescopes. It is generally true that, for the faint radio galaxies, both imaging and spectropolarimetric measurements have an uncertainty which is dominated by photon statistics. Instrumental polarization and other systematic effects are calibrated as well as possible and are generally below the 1% fractional polarization which can be reached in reasonable integration times for many of these sources. Considerable care, however, is needed in the analysis of these statistical errors for any particular observation. This is particularly true for polarimetry (as is well known by the protagonists of high precision stellar polarimetry) since several of the quantities of interest have asymmetric distribution functions and results can be severely biased at low signal-to-noise ratios (Fosbury, Cimatti and di Serego Alighieri 1994 and references therein). We have found that the best way of calculating the error distributions, both as part of data analysis and in the design of an observational strategy, is to perform Monte-Carlo simulations with a relatively detailed stochastic model of the particular observational setup. Estimators for the Stokes q and u parameters are better behaved that those for fractional polarization and position angle.

6 AGN at Very High Redshift

A close examination of the superb images of some HzRG which have been obtained with the Hubble Space Telescope Wide Field and Planetary Camera 2 (e.g., Fig. 6 and Longair, Best and Röttgering 1995) will give us a good idea of the problems we face in interpreting the state of these distant galaxies. To my knowledge, there has so far been *no* confirmed identification of a young stellar population in any HzRG. The continuum spectra above a rest wavelength of ∼4000Å appear to be dominated by an evolved, red stellar population and below 4000Å by the light responsible for the alignment effect (Rigler et al. 1992). The remarkably small dispersion of these objects in the K-band Hubble diagram (Lilly 1989, but see McCarthy 1993 for a recent review which includes more high redshift objects) also allows us to argue for an evolved stellar population although we must beware of strong emission lines moving into the photometric windows (Eales and Rawlings 1993).

A direct comparison of the K-band with the (rest-frame UV) HST images shows objects which are as different as chalk and cheese. This is beautifully consistent with the ensemble of polarization observations which show (Cimatti et al. 1993) the polarization 'switch on' as the observed passband (usually V or B) is moved by increasing redshift below the H and K break. In 3C 324 ($z = 1.2$, Longair, Best and Röttgering 1995) the position of the K-band nucleus occupies a central 'hole' in the very elongated HST image. It is clear from these pictures that, on the largest scale, these objects do not resemble the spectacular ionization cones seen in the Seyferts on the kpc scale. If the broad radiation cones are really there, they are not uniformly filled with matter which is, rather, distributed in a highly non-random manner. Although there is generally not a precise spatial coincidence between the radio source and the UV light (but see 4C 41.47, Miley et

Fig. 6. HST images showing the rest-frame ultraviolet images of three $z \sim 1$ radio galaxies with overlayed radio contours (courtesy Malcolm Longair, NASA and NRAO).

al. 1992), there are indications in some objects — and 3C 324 is a good example — that the light traces the path of the radio jet. This fact has often been used to argue the case for jet-induced star formation and, indeed, we cannot rule out the presence of blue stars in these regions which would dilute the fractional polarization of the scattered light. A salutary counter-example, however, is the $z = 0.811$ source 3C 265 which is misaligned with the radio source by about 35° and yet is highly polarized with an E-vector which is perpendicular to the UV extension (Jannuzi and Elston 1991; Dey and Spinrad 1995; di Serego Alighieri et al. 1996; Cohen et al. 1996) and *not* the radio axis. In some cases, emission beyond the radio lobes has been reported (van Breugel and McCarthy 1990; Eales and Rawlings 1993). Unless this material is the remnant of an earlier and now faded radio source, it must represent quiescent gas ionized by AGN photons.

A determination of the distribution of matter around these distant objects is crucial for coming to an understanding of their formation. The observations of the giant Lyα halo in the $z = 3.6$ radio galaxy 1243+036 (van Ojik et al. 1995) gives us a clue which I think helps us to draw some of the diverse threads together and begin to understand what is going on. The salient point here is the recognition of a component of the aligned EELR which is clearly associated with the (bent) radio structure and one which extends well beyond the radio source but is quite kinematically distinct. The gas contained within the region of the radio structure has a high velocity dispersion (∼1500 km/s FWHM) and, in particular, there is a blueshift at the point of the radio bend of 1100 km/s which coincides with a Lyα enhancement. The large scale ($20''$) halo, in contrast, has a velocity width of only 250 km/s and a global velocity gradient of 450 km/s. The faint extended UV continuum emission, while aligned with the principal (inner) radio axis, does not follow the bend in the structure.

I agree with van Ojik et al. that these observations argue strongly that the gaseous halo in 1243+036 must predate the AGN and its associated radio source. It also may go some way towards explaining the apparent dichotomy between those lower redshift EELR which appear to be smoothly rotating and those which appear chaotic: there may always be a component of the previously quiescent gas which has been disturbed after the birth of the radio source. The attraction of these quiescent halos is that they may represent material caught in the act of forming the galaxy. The presence of a powerful AGN illuminates the birth and give us opportunities for study which would be absent without the nuclear activity.

Having established the presence of a spatially extended scattered component which contributes to the alignment effect the polarization measurements are now being used as a major tool in attempts to separate out the different sources of radiation seen in these high redshift objects. Since the intrinsic fractional polarization of scattered radiation depends on the nature and on the geometrical configuration of the ensemble of scatterers, the measurement of the contribution of unpolarized diluting continuum is difficult. One technique, which has been applied to nearby Seyferts, is to look at changes in polarization across the scattered broad lines. An increase in polarization in the broad lines suggests a diluting unpolarized continuum called FC2 by Antonucci (1993, see also Binette, Fosbury and Parker 1993). This could be starlight or nebular continuum (Dickson et al. 1995).

The detection of broad, polarized lines in the aligned radio galaxies is now well established (di Serego Alighieri et al. 1996; Dey and Spinrad 1995) and in 3C 265, broad Mg II has even been seen in the extended component. They have also been seen in lower redshift objects like 3C 234 (Antonucci 1984; Tran, Cohen and Goodrich 1995) and Cygnus A (Antonucci, Hurt & Kinney 1994).

My conclusion is that, at these high redshifts, the nuclear radiation field is still playing a dominant role in the excitation of the extranuclear gas but that the spatial distribution of the material is influenced by the passage of the radio jet. I believe, however, that this may not constitute the whole story and CDM n-body simulations show us that the matter distribution over the scales of interest (100 kpc) was rather different at redshifts of a few from what it is now. Galaxies were forming within filamentary structures which, if illuminated by a powerful quasar, might look something like some of the aligned radio galaxies we see with HST rather than the filled ionization cones we see in the Seyferts on a much smaller scale.

Although I have been discussing the radio galaxies — objects with hidden quasars — there are some important implications for the work on quasar 'fuzz' which is directed towards the measurement of host galaxy properties. If scattering is redistributing a few percent of hidden quasar luminosity to make part or all of the continuum alignment effect in the galaxies, this scattered light will also appear in the quasar images. Indeed, if the scattering is from dust grains, the forward scattering which we would see when imaging a quasar could be a significantly larger fraction of the direct flux and so seriously contaminate any host galaxy starlight (Fig. 7). Without knowing the detailed distribution of the scatterers, this will be difficult to separate from the galaxy light and the colour information will be crucial.

Fig. 7. The geometry which produces the scattered, aligned light in the radio galaxies can also produce forward-scattered haloes in quasars. In the higher redshift, luminous quasars where any stellar host galaxy may be apparently faint in the rest-frame ultraviolet part of the spectrum, such scattered haloes can produce pseudo-hosts which contribute as much as 10% of the total quasar light.

7 Conclusions

The energy output of an active galactic nucleus has a profound effect on the state of its surroundings. The consequences of these interactions can be mapped on a scale of Mpc using the quasar absorption line 'proximity effect' and to a tenth of this in the radio galaxy extended emission lines. Studies of these phenomena have told us a great deal about the nature of the nuclei themselves and have allowed us to simplify our classification schemes for diverse AGN types. At the highest redshifts, AGN not only help us identify galaxies but they act as sources of illumination which enable us to study material in the process of forming galaxies.

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