THE AGN/NORMAL GALAXY CONNECTION : SUMMARY

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ABSTRACT

The connection between normal and active galaxies is reviewed, by summarizing our progress on answering nine key questions. (1) Do all galaxies contain massive dark objects (MDOs)? (2) Are these MDOs actually supermassive black holes? (3) Why are the dark objects so dark? (4) Do all galaxies contain an Active Galactic Nucleus (AGN)? (5) Are the “dwarf AGN” really AGN? (6) Does AGN activity correlate with host galaxy properties? (7) How are AGN fuelled? (8) Is AGN activity related to starburst activity? (9) How do quasars relate to galaxy formation?

INTRODUCTION

Twenty years ago Active Galactic Nuclei (AGN) seemed spectacular but rare objects, a kind of sideshow compared to the main astrophysical concerns of the geometry of the Universe, the formation of stars, and the origin of galaxies. Since then, quasars have become a standard cosmological tool; we have realised the close connections between the theoretical problems of star formation and the formation and fuelling of AGN; we have gathered strong evidence that every galaxy contains a weak AGN or a quiescent black hole; and there is a growing realisation that the nuclear activity and star formation histories of the Universe are closely linked. This COSPAR workshop has brought together a fascinating mixture of scientists to address these issues. The progress we have made and the distance still to go can be summarized by looking at nine key questions. In this review I will skim briefly over the surface of these nine questions.

DO ALL GALAXIES CONTAIN MASSIVE DARK DARK OBJECTS?

Although some of the most impressive cases for Massive Dark Objects (MDOs) have come from gas dynamics and masers (e.g. Marconi et al 1997; Miyoshi et al 1995) the most systematic searches have been the stellar kinematics studies. The review by Kormendy and Richstone (1995) found MDOs in 20% of E-Sb galaxies searched, and claimed a correlation between the mass of the dark object and the stellar mass of the bulge. However, to pass the rigorous filter of these workers (in particular excluding velocity anisotropy) conditions had to be favourable - MDOs are easier to confirm in edge-on strongly rotating bulges. The recent study by Magorrian et al (1998) of a large number of galaxies uses simplified modelling, justified by the results of the more rigorous studies. These authors find that almost all the galaxies they examine show clear evidence for central dark objects, and with a correlation between the mass of the object and the mass of the galactic bulge. Their average ratio (\(M_{MDO}/M_{bulge} = 0.006\)) is moreover twice that suggested by Kormendy and Richstone (1980).

Invited review presented in workshop session of the 32nd COSPAR Meeting, Nagoya, Japan 1998
“The AGN/Normal Galaxy Connection”, eds. H. R. Schmitt, A. L. Kinney and L. C. Ho.
To be published in Advances in Space Research (Oxford: Elsevier) 1999.
These are very exciting results but there are some caveats and worries. First, the evidence for ubiquitou sness comes almost entirely from the most massive early type galaxies, and so does not yet really tell us that all galaxies have an MDO, or that the mass correlation is really with bulge mass rather than total galaxy mass. Second, although the new survey has improved the MDO–bulge correlation, there is still a very large scatter in MDO size (two orders of magnitude) at any one galaxy size. Third, these are very large black holes compared to the sizes usually invoked in models of quasars and Seyfert galaxies.

There seems to be a genuine “relic problem”. Several authors have noted that the implied mass density in black holes is an order of magnitude larger than that expected from the integrated quasar light, and an assumed accretion efficiency of 10% (Phinney 1997; Haehnelt, Natarajan and Rees 1998; Faber, these proceedings). There are various possible explanations. Accretion efficiency may be much lower than we have assumed; the black holes may grow most of their mass in some early pre-quasar phase (Haehnelt, Natarajan and Rees 1998); or of course the MDO mass estimates may be wrong. There is however another very attractive possibility - that there exists a population of obscured quasars which outnumber normal quasars by a factor of several. Direct estimates of the number of obscured AGN are uncertain, depending sensitively on selection method (Lawrence 1991), but there is strong indirect evidence - current models of the X-ray background require obscured AGN to outnumber naked AGN by roughly 3 to 1 (e.g. Comastri et al 1995), and these numbers still do not include objects with columns in excess of a few times $10^{24}$ which will not contribute significantly to the X-ray background.

ARE THE MASSIVE DARK OBJECTS ACTUALLY SUPERMASSIVE BLACK HOLES?

The central massive objects are certainly dark - in most cases we can say that the mass-to-light ratio is at least several tens and sometimes hundreds, thus clearly ruling out normal stellar populations, but leaving other exotic possibilities such as a cluster of dark stellar remnants. The two most impressive cases are NGC 4258 and the centre of our own Galaxy, which are constrained on impressively small size scales and have large minimum central densities. In the case of NGC 4258, the motions of water masers are detected at radio wavelengths on milli-arcsec scales, implying a mass density of at least $4 \times 10^9 M_{\odot} \text{pc}^{-3}$ on a scale $r < 0.13$pc. Maoz (1995) argues further that the central object cannot be significantly extended without measurably distorting the perfect Keplerian rotation curve, implying a mass density of at least $5 \times 10^{12} M_{\odot} \text{pc}^{-3}$ on a scale $r < 0.012$pc. In our own Galaxy, the latest central mass estimates come from stunning observations of the proper motion of stars in the nuclear star-cluster which are consistent with movement around the radio source Sgr A* at speeds up to 1700 km s$^{-1}$. This has been made possible by shift-and-add image sharpening in the near-IR, first on the NTT (Eckart and Genzel 1996, 1997; Genzel et al 1997) and more recently on Keck (Ghez et al 1998; Morris, these proceedings). The new Keck data have 0.05" resolution and 0.002" positional accuracy; if monitoring is continued we can even expect to detect accelerations of the stars (Morris, these proceedings). The central dark object in the Galactic Centre has mass $2 \times 10^6 M_{\odot}$ within a radius of 0.01 pc, implying a minimum mass density of $10^{12} M_{\odot} \text{pc}^{-3}$ (Ghez et al 1998). Genzel et al (1997) have pointed out that the fact that SgrA* has no measurable proper motion in the (Galactic) radio frame strongly supports its identification as the location of the black hole, and indeed on statistical virial grounds this argues that its mass is at least $10^9 M_{\odot}$, so that SgrA* probably contains most of the mass causing the stellar motions.

At the very high minimum densities deduced in NGC 4258 and the Galactic Centre, any cluster of stellar-size dark objects will have a two-body relaxation time less than $10^6$ years, so that, following arguments along the lines of Begelman and Rees (1978), collapse to a black hole seems inevitable (e.g. Genzel et al 1997, Ghez et al 1998). We have reached a stage where from an astronomer’s point of view, the circumlocution “massive dark object” seems unnecessarily cautious. However from a physicist’s point of view this hardly seems proof of the existence of supermassive black holes. How close are we getting to the relativistic regime ? The directly measured size scales in NGC 4258 and the Galactic Centre are at roughly $10^4$ times the Schwarzschild radius in those systems. If we accept the argument of Maoz (1995) that the dark object in NGC 4258 can’t be distributed and is no larger than 0.01pc, we are still a factor of a thousand from the...
event horizon. If we make the assumption that the radio source SgrA* must be larger than the mass causing the stellar motions in the Galactic Centre, then we have reached 15 Schwarzschild radii - but of course this is not a safe assumption at all. If we accept the virial argument that SgrA* itself is at least \(10^5 M_\odot\), then the radio source covers 300 Schwarzschild radii (Genzel et al. 1997). But of course the virial argument is statistical (we might have been unlucky), and in a distributed model, there is no generic reason why the radio source can’t be smaller than the whole object. Probably the best evidence that we are actually dealing with black holes comes from the broad X-ray iron lines in active objects (e.g. Tanaka et al. 1995), where we seem to be seeing the signatures we would expect from rotation within a few Schwarzschild radii - very large velocities, a double peak with blue peak stronger, and the whole profile shifted to the red by gravitational redshift. Given the quality of the data, we should say that the evidence is extremely tempting rather than completely convincing, but hopefully AXAF and XMM will settle this question.

WHY ARE THE DARK OBJECTS SO DARK?

Fabian and Canizares (1988) first raised the worry that large black holes in elliptical galaxies ought to be extremely luminous from accretion of the hot gas that pervades such objects - but they are not. Likewise, the central sources in M31 and the Galactic Centre are extremely feeble; but gas is clearly present so one might expect luminosities many orders of magnitude larger than those seen (Goldwurm et al. 1994; Melia 1994). Meanwhile a parallel problem has arisen with the quiescent states of low mass X-ray binaries, where the deduced accretion rate from the companion star onto the disc should produce an X-ray luminosity orders of magnitude larger (e.g. McLintock et al. 1995; Lasota 1997). The solution proposed by several authors (Naryan and Yi 1995; Abramowicz et al. 1995; Fabian and Rees 1995) is the idea of the Advection Dominated Accretion Flow (ADAF), which may well be the natural state of affairs at very low accretion rates. Such flows are predicted to have very low efficiencies (thus solving the black hole darkness problem) and poor cooling, leading to electron temperatures of the order \(10^9\)K. The expected spectral energy distribution (SED) has two peaks, one from free-free in hard X-rays, and another from thermal synchrotron, together with secondary peaks due to Compton scattering. The magnetic field is deduced from pressure equipartition. Quite convincing ADAF models have been published for the Galactic Centre, for NGC 4258, and for soft X-ray transients (Narayan, Yi, and Mahadevan 1995; Lasota et al. 1996; Esin, McLintock and Narayan 1997; see also review by Narayan 1997). Until recently the available data have not tested the existence of the predicted GHz peak; however recent high frequency radio and sub-mm observations (Hernstein et al. 1998; Fabian, these proceedings) show that the ADAF models overpredict the observations by several orders of magnitude. It seems very hard for ADAF models to escape this blow.

What other possibilities can explain the darkness problem? Firstly, perhaps a significant fraction of the expected energy output could emerge as mechanical outflow rather than as radiation. This seems after all to be the case in SS433, where the mechanical luminosity is 1000 times larger than the X-ray luminosity (Watson et al. 1986). Secondly, accretion flow need not be steady. The possible mass supply to SgrA* from mass loss in the nuclear star cluster is on a scale of one parsec, \(10^5\) times the Schwarzschild radius. The dynamical timescale is of the order of a hundred years, but the flow time is likely to be much longer. These considerations may give us a reasonable idea of the time averaged accretion flow onto the outer accretion disc, but may not tell us the current accretion rate onto the black hole. There is a well known thermal instability which can lead to effective viscosity, and so accretion rate, changing by many orders of magnitude between high and low states. This is a popular explanation for dwarf nova and soft x-ray transient outbursts (e.g. Mineshige, Kim, and Wheeler 1990; Lasota 1997) and has been invoked to explain the quasar luminosity function (Siemiginowska and Elvis 1997).

DO ALL GALAXIES CONTAIN AGN?

We have known since the early 1980s that nearly all galaxies show nuclear emission lines, and that a third of all galaxies, and most early Hubble types, show LINER spectra, hinting at but not proving that some kind of weak quasar-like activity is extremely common (Heckman 1980). The heroic high S/N spectral
survey of 486 galaxies by Ho Filippenko and Sargent (1997 and references therein) has strengthened this suspicion, showing that \( \sim 10\% \) of galaxies show weak broad H\( \alpha \) lines, and almost half show AGN-like narrow lines. Meanwhile a very large fraction of elliptical galaxies show weak compact radio cores (Sadler, Jenkins and Kotanyi 1989; Wrobel and Heeschen 1991; Sadler, these proceedings.) It is now also becoming clear that a large fraction of very nearby galaxies contain weak nuclear X-ray sources (Colbert, Lira et al these proceedings). It seems that the large galaxies are more likely to contain AGN candidates - see later section. Given that star formation activity in late type galaxies could actually mask very weak quasar-like activity, it is increasingly tempting to believe that ALL galaxies contain some kind of AGN or AGN remnant. Of course the worry throughout about such objects (LINERS, weak radio sources, weak X-ray sources) is - are they really AGN?

ARE THE UBIQUITOUS LOW LUMINOSITY AGN CANDIDATES REALLY AGN?

Some LINERs have broad permitted lines and so are proper quasar analogues - but what about the very common objects that have only narrow LINER spectra? Ho (these proceedings) stressed that if the ratio of “LINER 2s” to “LINER 1s” is similar to the ratio of Type 2 to Type 1 Seyfert galaxies, then a large fraction of all LINERs would be explained. The expectation that LINER 2s can be obscured versions of LINER 1s has been spectacularly confirmed by the discovery of polarised broad H\( \alpha \) in NGC 1052 (Barth 1998, PhD thesis - diagram shown by Ho in these proceedings), showing the existence of an obscured BLR revealed in reflection, just as in NGC 1068. On the other hand, UV spectroscopy by Maoz et al (1998) of the compact UV sources seen in some LINERs shows very clear signatures of winds from hot young stars, showing that such objects contain young stellar clusters. Maoz et al show that those objects with clear stellar signatures are at least an order of magnitude less luminous in X-rays. It may be that LINERS are a genuinely heterogeneous class. On the other hand, the emission from such a young cluster could actually mask the presence of a very weak or obscured AGN.

The X-ray emission from broad-lined LINERs seems quite consistent with other properties (Koratkar et al 1995; Fabbiano 1996; Serlemitsos, Ptak, and Yaqoob 1996; Terashima et al 1997; Terashima, these proceedings) and indeed one cannot distinguish “dwarf AGN” whose narrow-line components are LINER-like from those whose narrow-line components are Seyfert-like. However worries have been raised that seem to distinguish dwarf AGN from more luminous objects like Seyfert galaxies and quasars. (i) It has been suggested that they do not vary, or vary less than Seyfert galaxies (Shields and Filippenko 1992; Ho, Filippenko, and Sargent 1996; Ptak et al 1998; Awaki, these proceedings). However the least luminous known AGN, NGC 4395, has been shown to vary rapidly, with colour changes just like those seen in Seyfert galaxies (Lira et al 1998). It may well be that NGC 4395, a dwarf galaxy, has a very small black hole, whereas many other LINERs have large black holes with low accretion rates. Further careful quantification is needed on the variability question. (ii) A second worry is that dwarf AGN tend to have no Big Blue Bump, but instead have steep optical-UV spectra, with \( \alpha \sim 2 \), and possibly also have a mid-IR excess compared to quasars (Ho, Filippenko and Sargent 1996; Barth et al 1996; Ho, these proceedings).

A possible explanation is dwarf AGN have very cool “bumps” rather than absent ones. Empirically, their steep spectra are consistent with the trends claimed by Kriss (1988), Wandel and Mushotzky (1989) and Zheng and Malkan (1993). Quasar SEDs systematically steepen from optical to UV, reaching \( \alpha \sim 2 \) in the far UV (Zheng et al 1997), and in any one spectral range steepen systematically as luminosity is lowered, from \( \alpha = 0 \) for the most luminous quasars to \( \alpha = 2 \) for dwarf AGN. Previous attempted explanations have concentrated on changing bump strength, but an attractive possibility is that characteristic temperature changes with luminosity. Lawrence (1998a) describes how multi-temperature models scale in a characteristic fashion and produce an excellent fit to the trends of SED shape with luminosity.

DOES AGN ACTIVITY CORRELATE WITH HOST GALAXY PROPERTIES?

One of the persistent facts about local AGN is that more or less without exception radio-loud AGN are
in elliptical galaxies, whereas radio quiet AGN are in spirals. There has been a debate about whether such a distinction continues to hold for the hosts of low-redshift quasars (see eg Taylor et al 1996 and references therein). The most careful study of quasar hosts so far is being undertaken with HST by Dunlop and collaborators. At this workshop, Kukula showed evidence that all the most luminous quasars live in giant ellipticals, regardless of radio loudness. However residuals from the smooth $r^{1/4}$ fits often show much disturbed structure suggesting mergers, complicating the interpretation. It has been suggested that mergers are central to the process of formation of both elliptical galaxies and quasars (Sanders et al 1988; Kormendy and Sanders 1989).

For many years there has been tantalising but not completely convincing evidence that quasar luminosity correlates with host galaxy luminosity (e.g. Lawrence 1993 and references therein). McLeod and Rieke (1995) have argued that rather than being a simple correlation between those quantities, there is an upper envelope to quasar luminosity which is proportional to galaxy size, and that quasars and Seyferts are consistent with the same relationship. In other words, big galaxies can have big or small AGN, but small galaxies can only have small AGN. A possible simple explanation is that black hole mass is on average proportional to galaxy mass (as local dynamical studies seem to indicate), but that a given black hole can have any accretion rate below a maximum given by the Eddington rate. The observed upper envelope is at least roughly consistent with that expected from the Magorrian et al $M_H/M_{bulge}$ relationship (McLeod 1997).

In their study of weak radio cores, Sadler, Jenkins and Kotanyi (1989) made essentially the same point concerning the wedge-like statistical relation between AGN power and galaxy luminosity, but went somewhat further, constructing the bivariate luminosity function, and trying various ways of quantifying the relationship, such as correlating galaxy luminosity $L_B$ with the 30th percentile radio power $P_{30}$. (Radio astronomers were always better at statistics ..) They found that $P_{30} \propto L_B^{2.2}$. On the other hand it seems that optical emission line strength is proportional to $L_B$ (Sadler, these proceedings; Sadler, Jenkins and Kotanyi 1989). Lira et al (these proceedings) have searched for weak nuclear X-ray sources in a volume limited sample of nearby galaxies. Nearly all the non-detections were in the smaller galaxies, and once again there appeared the all too familiar wedge-like pattern, consistent with the idea of an upper envelope to nuclear X-ray luminosity being proportional to galaxy luminosity. Of course we can’t be sure yet whether these weak X-ray sources are really AGN.

A significant puzzle, noticed by Sadler, Jenkins and Kotanyi, but now significantly strengthened, is that optical, X-ray, and emission line activity all seem to correlate roughly linearly with galaxy luminosity, whereas radio core power is much more sensitive, going as something like $L_B^{2-3}$. Whatever the explanation, this might help to make sense of the radio loudness dichotomy if the connection is specifically with spheroid component as often assumed.

HOW ARE AGN FUELLED?

A clear analysis of the fuelling problem is given in Shlosman, Begelman, and Frank (1989), and a useful collection of reviews, results, and theories can be found in the proceedings of the 1993 Kentucky conference Mass Transfer Induced Activity in galaxies (Shlosman 1994), and also in the proceedings of the 1996 Saas-Fee meeting, Galaxies: Interactions and Induced Star Formation (Kennicut, Schweizer, and Barnes 1998). It is an exceedingly difficult problem. Material has to change radial scale by perhaps nine orders of magnitude and lose something like five orders of magnitude of specific angular momentum. (Phinney 1994 makes this point particularly clearly not only in words but with a wonderful cartoon which I shamelessly stole for my talk at this conference). There is no shortage of ideas, most of which involve some kind of gravitational instability or non-axisymmetric potential. The problem becomes not so much “can it be done?” but rather “which of these ACTUALLY happens?” . However there will never be a simple theory of AGN fuelling. Each candidate process manages to shrink material by typically a factor of a few - so clearly a whole sequence of processes is needed. We can crudely divide the problem into four stages - (1) galaxy scale to central regions; (2) central regions to ten parsec scale; (2) ten parsec scale to accretion disc; (3) accretion disc to
event horizon.

Most of the observation and argument in recent years has concerned stage (1), and the role of interactions, mergers, and large-scale bars. It seems a particularly good bet that such processes are involved in triggering central starbursts. Most of this work concerns current day activity in existing galaxies, but some authors argue that the chaotic dynamics and clump interactions in the process of galaxy formation itself naturally leads to collapse of some central fraction of the gas, which may be closely related to the peak of quasar activity (Lake, Katz, and Moore 1998; Lake, Noguchi, these proceedings). Stage (2), from hundreds of parsecs to a few parsecs, has received less detailed attention. Theoretical possibilities include gravitational instabilities in the self-gravitating gas disk formed in stage (1), possibly as a cascade of bar instabilities (Shlosman, Frank and Begelman 1989); disruption of the disc by star formation; or magnetic braking (Krolik and Meiksin 1990). Some clues may be coming from gas morphology in the central regions. CO mapping of galaxies has shown that the central cold gas can have a variety of morphologies - rings, bars, central peak, twin peaks. These seem unlikely to be equilibrium dynamical structures and instead may tell us about the evolution of the central regions. Some important distinctions seem to be emerging - galaxies with AGN usually have CO rings and small ratios of gas mass to dynamical mass, whereas galaxies with HII spectra have CO bars and large ratios of gas mass to dynamical mass (Sakamoto et al. 1997; Ishizuki, these proceedings). This is a complicated subject but we may be close to putting together a feasible history of episodic collapse and star formation.

If Roberto Terlevich is right (e.g. Terlevich et al. 1992), stages (3) and (4) are not needed, as the AGN phenomenon is actually an exotic form of starburst on parsec scales in a high density environment. In the black hole model there is a long way to go to the event horizon, but somewhere on the parsec scale we will reach a point where the gravitational field of the hole dominates over the stellar field, so that the final fate of the material seems inevitable. It is tempting to believe that once a ten parsec scale gas disk has been produced in stage (2), it can fuel the black hole slowly and steadily by some local viscosity mechanism. However as explained by Begelman (1994) and Shlosman, Begelman and Frank (1989) such a giant accretion disc picture has serious problems - the inflow time is of the order of $10^9$ years or more, and the accretion rate will be too small to power quasar luminosities, unless the density is large, in which case the disc becomes gravitationally unstable to local clumping (in which case it will probably form stars, cease to dissipate, and so stop flowing in). It seems likely that even in this inner region, large scale (rather than local) gravitational or magnetic effects are needed to re-distribute angular momentum, which will probably happen in lurches rather than in a nice steady fashion. An interesting alternative is some kind of hot accretion flow, which can potentially support a faster flow and more mass without becoming unstable (Shlosman, Begelman and Frank 1989).

So far I have assumed that material needs first to be assembled from large distances. An alternative is that material is supplied from a nuclear star cluster. Early versions of such models explored disruption of stars (e.g. Hills 1975) but more recent work concentrates on stellar mass loss and supernovae, the fuelling from which will evolve with time following the formation of the cluster (Norman and Scoville 1988; Murphy, Cohn, and Durisen 1991; Williams and Perry 1994). Shlosman, Begelman and Frank (1989) argue that the supply rate from mass loss is unlikely to be enough to power luminous quasars. However if quasars are short-lived this may not be relevant, as the mass loss serves to accumulate a reservoir of material which can later be accreted. Strong support for developing models of this kind comes from the fact there is now good evidence that such compact nuclear star clusters really exist - for example in the Galactic Centre (Krabbe et al. 1995), in NGC 1068 (Thatte et al. 1997), and in a variety of other nearby galaxies (Ho 1997). It may be that this a late-stage phenomenon connected with recurring low-level activity in recent epochs; but it has also been suggested that the large abundances seen in high redshift quasars requires a starburst closely associated with quasars in both time and space (Hamman and Ferland 1992).

Finally we arrive at the accretion disc. This is a much more mature problem but cannot be considered completely solved. Reconsideration of the role of advection has recently shaken the subject up and the
origin of viscosity is still unclear. The most promising choice for viscosity is thought to be the Balbus and Hawley magnetic instability (Balbus and Hawley 1991) but in this case the disc will not behave at all like a standard “α disc”. Energy release will be above the disc rather than inside it (Begelman and De Kool 1991; Begelman 1994). Accretion is not necessarily steady. Indeed Siemiginowska and Elvis (1997) use predicted variations in accretion rate due to thermal instability to explain the quasar luminosity function.

Finally, an important generic point. At every stage of fuelling there is good reason to expect that activity will be episodic. As Krolik and Meiksin (1990) point out in their discussion of hundred–parsec scale magnetic braking, conservation of angular momentum demands that whenever some of the material goes in, other stuff goes out, so that reservoirs tend to evacuate as they “dump down” to the next stage. This naturally leads to episodes of accretion. The same basic point applies at all stages. Other feedback loops seem likely to operate. For example, various authors have suggested that in nuclear star clusters feedback between accretion, central radiation, winds, mass loss, and gravitational instability will lead to episodes of star formation, mass accumulation, and nuclear activity in turn (e.g. Bailey and Clube 1978; Williams and Perry 1994; Morris, these proceedings). Accretion discs may be subject to a thermal limit cycle (see earlier discussion), and accretion near the Eddington limit may be self-limiting and erratic. Finally, fuelling may be a stochastic event that occurs when one particular molecular cloud with low angular momentum intersects the black hole (Sanders 1981). An understanding of these time-dependent processes may be important for understanding quasar evolution.

IS AGN ACTIVITY RELATED TO STAR BURST ACTIVITY?

There is good circumstantial evidence that vigorous star formation is nearly always associated with quasar-like activity, and that much of the long-wavelength continuum energy distribution is actually from the starburst (Lawrence 1998 and references therein). But is there an actual causal connection? It may be that starbursts always precede AGN activity, in a grand sequence of galaxy interaction – infall – starburst – further infall – quasar (e.g. Sanders et al 1988). On a smaller scale, parsec scale starbursts may always be closely connected with quasar-like activity with the causal connection going in both directions (see previous section) and indeed it has been argued that parsec scale starbursts could be the whole explanation of quasar-like activity (Terlevich et al 1992). Alternatively the large and small scale processes could be separate phenomena. Perhaps galaxy mergers cause starbursts which collapse no further, whereas AGN activity and fuelling is entirely connected with small scale structures formed at early times. This is one reason why we would still like to answer that fashionable question of the late 80s - are the ultraluminous IRAS galaxies (which are very frequently mergers) really starbursts or are they obscured AGN? Mid-IR spectroscopy from ISO seems to show clear cases of each, but with most objects being starbursts and a large minority being AGN (Genzel et al 1998; Lutz et al 1998). X-ray studies also suggest a mixture (Rigopoulou et al 1995; Nakagawa, these proceedings). Re-assuringly, mid-IR and X-ray classifications seem to agree reasonably well (Lutz, these proceedings). As one might have guessed, ULGs are a heterogeneous class, so one must be careful drawing conclusions from them.

HOW DO QUASARS RELATE TO GALAXY FORMATION?

The peak of quasar activity at z=2-3 is suspiciously similar to the predicted epoch of spheroid formation in cosmological theories, suggesting a close connection between quasars and galaxy formation (e.g. Efstathiou and Rees 1988, Haehnelt and Rees 1993). Of course one (probably) needs a galaxy before one can get a quasar; the subsequent decline may be connected with a decline in fuelling (e.g. Small and Blandford 1992) but this is not yet clear. Alternatively some authors have suggested that quasar activity actually has a causal role in triggering or inhibiting galaxy formation (Chokshi 1997; Silk and Rees 1998). Our perspective on such questions is changing rapidly. For three decades quasar evolution was a hard observed fact, whereas galaxy formation was a theoretical blur. This situation is now changing dramatically as galaxies are being detected at high redshift, and we can begin to construct the cosmic history of the star formation rate (Madau et al 1996). It has been noted that the evolution of quasar luminosity density tracks the cosmic star formation rate
very closely (Dunlop 1997; Boyle and Terlevich 1998). Silk and Rees (1998) argue that the star formation rate peaks later ($z=1-2$) than quasar activity, and suggest a feedback loop between winds from early quasars and spheroid formation. However, it now seems clear that the high-redshift star formation rate is higher than had been thought. The optically selected high-$z$ sources have significant reddening (Pettini et al. 1997) and the star formation rate deduced from the new population of faint sub-mm sources is a factor of several higher, improving the close agreement with the shape of quasar luminosity density evolution (Hughes et al. 1998, Blain et al. 1998).

The faint sub-mm sources are generally assumed to be starbursts, the most striking conclusion being that most star formation at early times is occurring at any one time in a small number of luminous bursts. But could the faint sub-mm sources be AGN? Almaini, Lawrence and Boyle (1998) calculate predicted obscured AGN counts in the sub-mm (by requiring that the number of obscured AGN matches that required in X-ray background models) and find that around 5 - 20% of the detected sources are probably AGN. This number is sensitive to assumed cosmology and the form of high-$z$ evolution, such that this fraction is very uncertain, and likely to increase to even fainter fluxes. Whether the faint sub-mm sources are starbursts or quasars, they are certainly things going BANG, and such objects dominate the energetics of the young universe. This is in strong contrast to today, when the luminosity density in AGN and starbursts combined is a tiny fraction of the total galaxian luminosity density. History belongs to the heroes, but the meek shall inherit the Earth.

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