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Starburst galaxies—AGN connection : theoretical scenario

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Abstract. Starburst galaxies are characterized by a very high central infrared luminosity of about 10^{10}-$10^{12} L_\odot$. This luminosity is attributed to a burst of formation of massive stars. The stellar radiation is absorbed by dust and re-radiated thermally in the infrared. Active Galactic Nuclei (AGN) are very energetic, non-thermal, compact nuclear sources believed to be powered by accretion of gas onto the central black hole. Both, starburst galaxies and AGN, are seen to occur preferentially in interacting field galaxies. A galaxy interaction causes gas infall from the disk, which may lead to the triggering of a central starburst which could then evolve to an AGN, or the gas infall may fuel a pre-existing central black hole. Starburst galaxies and AGN are both vast and extremely active areas of research today. Here, first the basic physical properties of starburst galaxies and AGN are highlighted. Next, some simple theoretical ideas regarding the evolution of starbursts to AGN are discussed. Implications of the starburst-AGN connection for the evolution of the quasar luminosity function are mentioned.

Key words: starburst galaxies—AGN—quasar

1. Starburst galaxies

Starburst galaxies are characterized by very high luminosity $\sim 10^{10}$-$10^{12}\ L_\odot$ in the far-infrared ($\sim$30-300μ), seen typically over the central region of $\sim$1 kpc diameter. This is about 10-10^3 times the central infrared luminosity from a quiescent galaxy like our Galaxy. A major part of luminosity in these galaxies is in the infrared region. A star formation rate (SFR) of $\sim$10-100 $M_\odot \mathrm{yr}^{-1}$ is required to explain the above high luminosity values. At this rate, the gas in a galaxy would be exhausted in $\leq 10^8$ yr which is much smaller than the lifetime of a galaxy. Hence the luminous phase must be a transient phenomenon and therefore, galaxies showing a high infrared luminosity are said to be undergoing a starburst. The infrared luminosity is believed to be from young, massive stars which are therefore still near the sites of formation, namely, the gas clouds. Hence the stellar radiation is absorbed by the dust in the clouds, and re-radiated thermally in the far-infrared. The subject of starburst galaxies can be said to have been truly launched after the data from IRAS became available in the mid-1980's.

Starburst galaxies are often seen in interacting field galaxy pairs (e.g. Joseph *et al.* 1984; Lonsdale *et al.* 1984), as indicated by the presence of nearby neighbours, or from their disturbed morphology and tidal tails which indicate a recent interaction. Galaxy interactions play a major role in triggering starbursts and also in the formation and/or fuelling of AGN. First, a galaxy-galaxy interaction has a dramatic effect on the dissipational component (gas) in the galaxies. A galaxy interaction leads to an increase in the effective viscosity and hence an infall of gas from the galactic disk to the central regions, which then may result in a starburst. Second, it is now realized that galaxy interactions are very common. From the number of merging pairs in the NGC catalog and the lifetime of mergers it can be argued that as many as ~5% of galaxies undergo mergers in their lifetime (Toomre 1977). Recent estimates give a higher value for merging fractions (Schechter 1990). A much larger fraction undergoes distant or a tidal interaction.

The main observational features of starbursts are high values of : (1) Central infrared luminosity, $L_{\mathrm{IR}} \sim 10^{10}\text{-}10^{12}\, L_{\odot}$; (2) $L_{\mathrm{IR}}/M_{\mathrm{gas}} \sim 1\text{-}30\, L_{\odot}/M_{\odot}$; (3) infrared excess, $L_{\mathrm{IR}}/L_{\mathrm{B}} \sim 0.1\text{-}60$; (4) H_{α} luminosity, $\sim 10^{40}\text{-}6 \times 10^{42}$ erg sec^{-1} and strong optical emission lines from ionized gas; and (5) Unusual (redder) colours, see e.g. Telesco (1988), Jog & Solomon (1992) for details. The low values of these parameters in the above range are typical for tidally or weakly interacting galaxies such as M82, while the higher values represent the evolved mergers such as Arp 220. The high values of L_{IR} indicate a high SFR as discussed above. $L_{\mathrm{IR}}/M_{\mathrm{gas}}$ is an indicator of the star formation efficiency (SFE). SFE is estimated to be high ~10-30% (e.g. Rieke *et al.* 1980) versus a few % in a quiescent galaxy like our Galaxy. The high values of L_{IR}, $L_{\mathrm{IR}}/L_{\mathrm{B}}$, H_{α} luminosity; the strong emission lines, and the redder colours indicate a recent burst of formation of massive stars.

To summarize, starbursts are characterized by a high SFR and a high SFE, and a preferential formation of massive stars. That is, the initial mass function (IMF) is biased towards massive stars, or the minimum mass of stars formed is $\geq$ a few $M_{\odot}$ each. This is confirmed by theoretical models (Rieke *et al.* 1980). A preferential formation of massive stars allows the gas reservoir to support a burst longer because the luminosity per unit mass is a non-linear, increasing function of the stellar mass. For the details of physics for the origin of the high SFE and the preferential formation of massive stars in the high-density shocked gas, see Jog & Solomon (1992).

Surprisingly, the origin of the triggering of starbursts has not received much attention in the literature. Most of the theoretical work so far has been concentrated in showing that galaxy interactions can lead to gas infall from the galactic disk to the central regions (e.g. Hernquist 1989). But the detailed physical treatment for the triggering of starbursts is mostly missing. The increased central gas concentration is assumed to lead to an increase in cloud collisions which then result in an enhanced formation of massive stars (e.g. Norman & Scoville 1988). While this is plausible, there are several problems with this approach, see Jog & Das (1992) for details. For example, theoretical hydrodynamical simulations show that high velocity and/or off-centre cloud collisions lead to their overall disruption rather than compression (the latter would lead to star formation) (see Lattanzio 1990).

An alternative triggering mechanism that is based on the evolution of a realistic, multi-component interstellar medium has been proposed by Jog & Das (1992). As a pre-existing disk giant molecular cloud (GMC) tumbles into the central region following a galaxy interaction, it arrives in the pre-existing high-pressure central gas reservoir. The GMC is barely stable to begin with. The over-pressure due to the central gas (the molecular intercloud medium) then causes a radiative shock compression of the outer shell of the GMC. The compression continues until the crossing time is less than the onset of instabilities in the shocked shell.

This shocked shell then fragments and forms massive stars. The resulting luminosity depends on the fraction of cloud mass compressed, the efficiency of star formation in the shocked gas, and the rate of gas infall from the disk to the central region. The results agree fairly well with the observed values of $L_{\rm IR}$ and $L_{\rm IR}/M_{\rm gas}$ (see Jog & Das 1992). This quantitative analysis was possible because realistic, observed pre-encounter gas parameters as in our Galaxy were used here. Future work must include even more detailed gas dynamics such as the effects of clumpy nature of the clouds.

The complementary case of early stages of mergers where the star formation occurs *in situ* in regions of overlap (as for example in Arp 244 or in Arp 299) can also be explained by the overpressure idea (Jog & Solomon 1992). The overpressure in this case is provided by the remnants of collisions of atomic hydrogen clouds from the two galaxies—this is a dynamic problem and the duration of starburst is set by the galaxy crossing time.

So far, the effectiveness of galaxy interactions in triggering starbursts has been highlighted. Note, however, that nearly 30% of interacting galaxies do not show starbursts (Bushouse 1986). Conversely, isolated, barred galaxies may show starbursts. Jog & Das show that if the galaxy does not have a high-pressure central gas to begin with, then despite gas infall due to a bar or an interaction, the galaxy would not display a starburst—as is the case in M 33. Conversely, an isolated, barred galaxy such as IC 342 where the bar causes the gas inflow may show a starburst if it has a high-pressure central gas reservoir.

The subject of starburst galaxies is a very active and exciting field today. Starbursts galaxies are interesting in themselves as sites of high formation rates of massive stars and high SFE. Moreover, they also have important implications for a number of fields in astronomy. First, since preferentially massive stars are formed, as they evolve and die they will cause a metal enrichment of the host galaxies. This is especially important for the early, chemical evolution of the primordial galaxies and also for the inter-galactic medium. Second, the supernovae resulting as the end states of massive stars are expected to lead to substantial energy input into the dynamics of the interstellar medium. Third, ultraluminous starburst galaxies are believed to be precursors of AGN (see section 3).

2. Active galactic nuclei (AGN)

The title AGN has by now come to denote a bewildering zoo of objects with little similarity at first glance. These have attracted vast amounts of work and have been studied in all the wavelength bands from radio to X-ray to γ-rays over the last thirty years. The ever increasing amount of research on this has only revealed the fascinating complexity of the subject. Although the various AGN seem dissimilar at first glance, there are several common physical characteristics which unify these (e.g. Begelman 1988; Netzer 1990). These are :

1. *Compact, central energy source* : This is evident from the short time scale variability especially in the X-ray region. The size of AGN is dependent on the wavelength under consideration, with the more energetic emission being more centrally concentrated.

2. *Large rates of energy output* : The large central rate of energy output seen often far surpasses other (stellar) energy sources within the galaxy.

3. *Non-thermal central energy source* : The central source shows a non-thermal, flatter spectrum compared to the standard thermal spectrum from stars.

4. *Large line-widths* : The central gas moves rapidly as seen from the large line-widths of the gas emission. This implies motion in a deep potential well.

These characteristics have now come to define an AGN. Of course, there is a tremendous variation in the values of these parameters amongst the various types of AGN. However, these properties show a smooth variation, with overlap amongst the various classes. This means that these properties do represent basic physical characteristics, and hence can be used as meaningful classification parameters.

For example, if one were to categorize the AGN on the basis of the total central luminosity (L_t), then the AGN can be divided into the following three groups (Netzer 1990): (1) Quasars and QSO's (radio-quiet quasars) with $L_t \sim 10^{45}$-10^{47} erg sec^{-1} ~ 10^{12}-10^{14} $L_\odot$. These are the most energetic AGN. (2) Mini-Quasars : Seyfert 1, and Seyfert 2, with $L_t \sim 10^{43}$-10^{45} erg sec^{-1}. (3) Micro-Quasars : Liners, with $L_t \sim 10^{41}$-10^{43} erg sec^{-1}. The L_{IR} values for the starburst galaxies overlap with the L_t values for the micro- and mini-quasars. The number of Quasars and QSO's is much less than that of the Seyferts which in turn are much less numerous than the Liners. In fact, almost all large, barred, early type galaxies show evidence for the phenomenon of Liners (line ionization nuclear emission regions).

Although the detailed physics of AGN is complex and not well-understood, their basic characteristics described above can be best explained by the following *standard model.* The central, non-stellar power source of an AGN is believed to be a massive black hole, powered by accretion of gas from the surrounding host galaxy. This can explain the compact nature, the high rates of energy output (since the conversion from mass to energy is very efficient in the relativistic potential as compared to that in the star formation process), the non-thermal energy spectrum, and the large line widths. Over the last ten years it has been shown that AGN occur preferentially in interacting pairs of field galaxies or in groups of galaxies—as seen for Seyferts (e.g. MacKenty 1990), and also for QSO's (Stockton 1990). This implies that the formation and/or fuelling of central black holes in AGN must be favoured by galaxy interactions.

The fuelling of the central black hole in an AGN is a major theoretical problem. The problem can be divided into the availability of gas fuel in the galactic disk, and the transport of this fuel from the disk to the central regions. It turns out that the total amount of available fuel is more than adequate. For example, in order to support luminosity of even the most luminous AGN—that is, quasars and QSO's (with $L_t \sim 10^{45}$-10^{47} erg sec^{-1}), one would need a gas accretion rate of about 1-100 $M_\odot$ yr^{-1} onto a canonical black hole mass of ~10^8 $M_\odot$ (e.g., Shlosman *et al.* 1990). At this rate, the gas in a typical spiral galaxy will be able to support the central AGN luminosity for about ~10^7-10^{10} yr. Therefore, the main problem is how to transport this material from the disk into the central regions. In a gravitating, differentially rotating disk, the specific angular momentum (or the angular momentum per unit mass) increases with the radial distance. Hence the gas infall from a region of high specific angular momentum at high radial distances to the central regions has to be associated with an outward transport of angular momentum in the disk. This is a standard problem in the evolution of dissipational, differentially rotating disks encountered in a number of contexts in astronomy, e.g., in planetary rings.

Galaxy interactions can help in this because they increase the cloud collision rates and also they can cause formation of spiral features in the disks. The resultant increase in the effective viscosity in the disk leads to a higher gas infall rate, since the infall rate is set by the viscous dissipation rate. The net evolution of a viscous disk results in most of the gas falling in while a small amount of matter is transported outwards (Lynden-Bell & Pringle 1974). Non-axisymmetric perturbations in the disk (which could be caused by the interaction) or the central bars in the disk will also have the same dynamical effect via more subtle wave-particle interaction and also the dissipation of cloud motions in such potentials (Norman 1992).

3. Starburst galaxies—AGN connection

There are at least three possible causal connections between starbursts and AGN :

1. *Starbursts evolving to AGN* (i.e., Starbursts as progenitors of AGN) : There is clear evidence for this case, and I will mainly concentrate on this.

2. *AGN triggering starbursts in the host galaxy* : It is often hard to separate out this case from case 1. Surprisingly, there is clearer evidence for starbursts triggered in the host galaxy by the AGN jets for the high redshift systems (e.g. Kapahi 1993). It is possible that galactic environment is different early on which allows this connection to be established.

3. *Starbursts mimicing AGN* : This is an alternative to the standard model where the central starburst with hot Wolf-Rayet stars is said to explain all the observed properties of an AGN (Terlevich & Melnick 1985), and is mentioned here for the sake of completeness. While this explains some radio properties for specific objects well (Saikia 1993), it cannot explain the observed fast variability in X-rays, or the line ratios which are indicative of non-thermal emission, or the luminosity of the most luminous quasars (Osterbrock 1991).

3.1. *Central starbursts as progenitors of AGN*

This is the case 1 mentioned above and will be discussed in detail next. Such a causal connection is expected because, first, both the phenomenon are centrally concentrated in a galaxy—although the AGN phenomenon is more centrally concentrated than the starbursts. Second, both phenomena are seen more often in interacting galaxies. Galaxy interactions could either fuel a pre-existing black hole, or lead to a central starburst which could then evolve into an AGN.

Weedman (1983) was the first to propose this causal connection although in retrospect it now seems obvious. He proposed that if a large number of massive stars form fast, in a small central volume—then the compact stellar remnants from these could act as accretors. These remnants could evolve via dynamical friction, and settle into a small nuclear volume. Thus the nuclear region would evolve to be an AGN, with a net luminosity as in a Seyfert 1 galaxy. All the above initial conditions required for the evolution of a central starburst to an AGN are satisfied in a typical starburst since they have a high SFR and high SFE and show a preferential formation of massive stars (see section 1).

Weedman further argued that the timescale required for dynamical equilibrium of the stellar remnants is smaller than the the duration of starburst, hence starbursts and AGN may be seen simultaneously in some cases. There is clear observational evidence for such composite nuclei in some galaxies. The nearby Seyfert NGC 1097 can be optically resolved into a central AGN nucleus and an extended 3 kpc diameter central ring showing starburst activity (Keel 1985). The host galaxies of QSO's, such as 3C 48, also show evidence for starbursts as evident from their distorted morphology and unusual colours (Stockton 1990). However, it is not clear from the studies of these composite nuclei whether there is a serious causal connection between the starburst and the AGN phenomena or whether there is merely an overlap of these phenomena. In the latter alternative, the two phenomena may show correlations simply because both could be fuelled by the same processes—namely galaxy interactions or central bars.

The classic study by Sanders *et al.* (1988) shows clear evidence for starbursts as being precursors to AGN. Sanders *et al.* studied a sample of 10 ultraluminous galaxies detected from IRAS. These are the most luminous of all the known IR-bright galaxies. The limiting luminosity for this sample was chosen to be $10^{12}\,L_{\odot}$ since this is the limiting (optical) bolometric luminosity of QSO's and since the authors wanted to see if there was any connection between starbursts and AGN. They systematically studied a number of diagnostics for physical parameters that would distinguish between a starburst and an AGN as the power source—namely, the slope of the continuum spectrum, the optical emission line ratios, $L_{\rm IR}/M_{\rm gas}$, and the linewidth for the H_α line. 90% of their sample showed clear evidence for an AGN as being the dominant power source. They also showed that as $L_{\rm IR}$ increases, these properties show a smooth progression from starburst-dominance to AGN-dominance (in terms of strength of these properties and also the % of galaxies showing these). Also, the % of interacting galaxies increases with increasing $L_{\rm IR}$.

Sanders *et al.* conclude that these ultraluminous galaxies represent a stage in the evolution of merging galaxies where the AGN (a Seyfert) is the dominant energy source, which was presumably formed and/or fed by the strong galaxy interactions. They further claim these to be dust-enshrouded or buried QSO's (in early stages of formation) with $L_{\rm IR}$ values $\sim L_{\rm t}$ values seen in the optical in typical QSO's. They outline a simple picture of the evolution from an ultraluminous starburst to an AGN. A galaxy interaction is assumed to lead to gas infall followed by a central starburst. The supernova explosions resulting from the starburst, the stellar winds, and the radiation pressure from the AGN are claimed to remove the dust shroud and the host galaxy then appears as a standard UV/optical dominated QSO. However, their model does not give energetics of the dust heating or removal, nor the effects of dust on the spectrum from an AGN. Further, gas could also be removed via the same processes (Chevalier & Clegg 1985) (see section 3.2). Most seriously, it is not clear if dust removal is sufficient for these galaxies to evolve into QSO's. The potential depth is different in the two cases and it is not clear how removal of dust from a Seyfert nucleus can give rise to the large line widths for the emission lines seen from the broad line region of a QSO. Thus, while the starburst to a Seyfert causal connection seems well established observationally, the subsequent evolution from a Seyfert to a QSO as claimed by Sanders *et al.* is not as convincing.

This picture is explored in more detail by Norman & Scoville (1988). They assume that a galaxy interaction leads to the formation of a central star cluster of $\sim 4 \times 10^9\,M_{\odot}$ in the central 10-50 pc. The stellar outflows from this feed the AGN. The radiation pressure from the AGN ionizes the stellar mass-loss envelopes which thus produce the BLR features as seen in QSO's. The main problem with this model is that it starts out with unrealistic initial conditions. By assuming such a massive central star cluster in the central 10-50 pc, the main problem of getting the gas so far in has been bypassed. Once such a massive star cluster forms, their model may be viable. Further, the central starburst is typically seen over the central 1 kpc, and not 10 pc as they assume (Frank 1990).

3.2. *Future work*

Therefore, the evolution of a starburst into a full-fledged AGN still remains an open problem. A self-consistent solution to this problem is complex, one reason being that the overall AGN phenomenon is not fully understood. However, there are a number of well-defined, challenging theoretical problems in this area that need to be done. These are as follows :

1. *Gas infall problem* : The various dynamical aspects of gas infall from 10 kpc to 1 kpc, and especially from 1 kpc to 1 pc have yet to be worked out (e.g. Frank 1990; Shlosman *et al.* 1990). Lin, Pringle & Rees (1988) have studied fuelling of an AGN with the gas being driven in from 1 kpc to 1 pc via gravitational instabilities. However, this requires too large a central gas content ($\sim 10^{10}\ M_\odot$). A general problem is that the infall time is proportional to the dynamical time which is smaller at lower radii, hence establishing a steady supply of gas all the way into the central 1 pc is difficult (Frank 1990).

The rate of central accumulation of gas also depends on the initial distribution of gas. Most starbursts and Seyferts are barred galaxies with central gas holes, and yet theorists doing infall calculations generally use a centrally peaked gas distribution which would increase the gas infall rate, as pointed out by Shlosman *et al.* (1990). Also for simplicity, work on gas infall has been mainly confined to spiral galaxies.

2. *Microphysics* : Microphysics, especially gas dynamics, in the central region needs to be worked out. This could involve hydrodynamic studies of cloud collisions especially those that include radiative losses, shocks in clumpy clouds (see section 1), gas motion in the bar potential, and so on.

3. *Feedback from the central starburst on the host galaxy* : Supernovae resulting from a starburst can set up a wind in the surrounding host galaxy with a wind velocity of ~1000 km s^{-1}, which can clear a hole of radius few 100 pc (Chevalier & Clegg 1985). These superwinds have now been observed. Thus the fuelling of a starburst/AGN in presence of an interaction or a bar is a self-supporting and in the end also a self-limiting process. A very high star formation rate would lead to a fast removal of a large amount of the central gas via winds. The question then is whether one can have fuelling despite the disruptive feedback from the central region? The infall models so far have not taken account of this effect.

The effect of AGN on the host galaxy is even more important given its energetic output over a large range of wavelengths. For example, Begelman (1988) has studied the effects of X-rays from a Seyfert on the ISM of the host galaxy.

The point is, what you see in an AGN is after all a net effect of fuelling via gas inflow, and the AGN outflow and its effect on the host galaxy. Hence unless the effect of the AGN outflow on the host galaxy is understood clearly, it would be hard to check if the starburst → AGN connection is indeed valid.

4. *Evolution of the central star cluster* : The dynamical evolution of the compact stellar remnants from the central starburst (Weedman 1983), possibly with the formation of the central massive black hole, has to be worked out in detail.

4. Implication for high redshifts

The above discussion on the starburst → AGN connection has important implications for high redshift galaxies. Both the phenomena are expected to be more frequent and more luminous early on. This is because the number density of galaxies are expected to increase with redshift, and the galaxies are expected to be more gas-rich early on. Hence both the frequency and the effectiveness of encounters is believed to be higher early on. This can naturally explain the observed evolution of the quasar luminosity function as argued next.

It is well known that the comoving number density of quasars and QSO's (radio-quiet quasars) increases dramatically with the redshift z and peaks at $z \sim 2$ and falls beyond that—see Schmidt (1989). The evolution of the cumulative number density above a limiting luminosity (also known as the quasar luminosity function) with z is not a purely observational result. If anything, the typical absolute luminosity of a QSO increases with z (Warren & Peacock 1990). This implies that either most quasars formed at higher redishifts (and were short-lived) or that they were more bright at higher redshifts. The evolution of the quasar luminosity function can be well explained qualitatively by the interaction/merger picture. It could be a pure luminosity evolution due to the higher fuelling rate likely at high z due to the galaxies being gas-rich then. Or it could be explained as a combination of luminosity and number evolution—since the frequency of encounters is expected to be higher early on as explained above. The decrease in numbers at $z > 2$ is taken to imply that galaxy formation occurred at around $z = 2$ or just before that (Schmidt 1989).

Several models have been proposed to explore this idea (e.g. Carlberg 1990). However, these have too many parameters by necessity and hence do not give a unique scenario. Apart from all the problems associated with the gas infall problem, here there are additional uncertainties, such as the epoch of galaxy formation, the number and duration of starbursts. Most importantly, the structure of galaxies at high redshifts is a big unknown. In this context, the recent near-infrared photometry work for high redshift galaxies (e.g. Kapahi 1993) is very important. At the high redshifts of 2-3, this corresponds to the rest-frame optical wavelengths and hence near-IR photometry of these galaxies will give information on the structure of high redshift galaxies, which will act as important constraints for these models.

Thus the fields of starbursts and AGN both promise to remain active and exciting for quite some time. Hopefully, the starburst-AGN connection will become clearer in the next few years. As in the past, a strong interaction between theorists and observers will lead to a faster and meaningful progress in this field, and help obtain a cohesive, global picture.

References

Begelman M. C., 1988, in : Origin, Structure and Evolution of Galaxies, ed. F. Lizhi, World Scientific, p. 227.

Bushouse H. A., 1986, AJ, 91, 255.

Carlberg R., 1990, ApJ, 350, 505.

Chevalier R. A., Clegg A. W., 1985, Nature, 317, 44.

Frank J., 1990, in : Structure and Emission Properties of Accretion Disks, ed. C. Bertout, Editions Frontiers, p. 135

Hernquist L., 1989, Nature, 340, 687.

Jog C. J., Das M., 1992, ApJ, 400, 476.

Jog C. J., Solomon P. M., 1992, ApJ, 387, 152.

Joseph R. D., Meikle W. P. S., Robertson N. A., Wright G., 1984, MNRAS, 209, 411.

Kapahi V. K., 1993, BASI, 21, Nos. 3 & 4.

Keel W. C., 1985, in : Astrophysics of Active Galaxies and Quasi-Stellar Objects, ed. J. S. Miller, University Science Books, p. 1.

Lattanzio J. M., 1990, in : Nonlinear Astrophysical Fluid Dynamics, eds. J. R. Buchler & T. Gottesman, Ann. N.Y. Acad. Sci. 617, p. 158.

Lin D. N. C., Pringle J. E., Rees M. J., 1988, ApJ, 328, 103.

Lonsdale C. J., Persson S. E., Matthews K., 1984, ApJ, 287, 95.

Lynden-Bell D., Pringle J. E., 1974, MNRAS, 168, 603.

MacKenty J. W., 1990, ApJS, 72, 231.

Netzer H. A., 1990, Active Galactic Nuclei, Saas-Fee 20, Springer-Verlag, p. 57.

Norman C., 1992, in : Massive Stars in Starbursts, eds. C. Leitherer & N. Walborn, Cambridge Univ. Press.

Noman C. & Scoville N. Z., 1988, ApJ, 332, 124.

Osterbrock D.E., 1991, Rep. Prog. Phys., 54, 579.

Rieke G. H., Lebofsky M. J., Thompson R. I., Low F. J., Tokunaga A. T., 1980, ApJ, 238, 24.

Saikia D. J., 1993, BASI, 21, Nos. 3 & 4.

Sanders D. B. *et al.*, 1988, ApJ, 325, 74.

Schechter P., 1990, in : Dynamics and Interactions of Galaxies, ed. R. Wielen, Springer-Verlag, p. 508.

Schmidt M., 1989, Highlights of Astronomy, 8, 33.

Shlosman I., Begelman M. C., Frank J., 1990, Nature, 345, 679.

Stockton A., 1990, in : Dynamics and Interactions of Galaxies, ed. R. Wielen, Springer-Verlag, p. 440.

Telesco C. M., 1988, ARA&A, 26, 343.

Terlevich R., Melnick, 1988, Nature, 333, 239.

Toomre A., 1977, in : The Evolution of Galaxies and Stellar Populations, eds. B. M. Tinsley & R. B. Larson, Yale Univ. Press, p. 401.

Warren S. J., Peacock P. L., 1990, Rep. Prog. Phys., 53, 1095.

Weedman D. W., 1983, ApJ, 266, 479.