The Neutral ISM in Starburst Galaxies
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From Gas to Starburst and AGN

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Abstract.
Although it is clear that the circumnuclear regions of galaxies are intimately related to their host galaxies, most directly through their bars, it remains unclear what exactly initiates and fuels nuclear stellar (starburst) and non-stellar (AGN) activity. Deviations from axisymmetry in the gravitational potential of a galaxy, set up by a bar or an interaction, are known to cause gas inflow, and must at some scale and level be related to the fueling of AGN and starbursts. We review the observed relations between bars and interactions on the one, and nuclear activity of the Seyfert and starburst variety on the other hand, and conclude that none of these relations is particularly significant in a statistical sense, except in extreme and rare cases, such as ultra-luminous infrared galaxies. Nuclear rings of star formation, however, are not only related directly to non-axisymmetries in the potential, but also, it seems, to the occurrence of nuclear activity. Their role as potential tracers of the fueling process must be further explored.

1. Introduction

Nuclear activity in galaxies, either of the stellar (a nuclear or circumnuclear starburst) or non-stellar ("active galactic nucleus"; AGN) variety, is rather common in present-day galaxies (e.g., Ho, Filippenko, & Sargent 1997a). The most tangible link between the nuclear regions and the host galaxy is provided by the fact that the mass of the central supermassive black hole in a galaxy is directly related to the velocity dispersion (hence the mass) of the bulge (Ferrarese & Merritt 2000; Gebhardt et al. 2000). Since such black holes appear to be ubiquitous in the nuclei of both active and non-active galaxies (Kormendy & Richstone 1995), whether or not a galaxy is active must largely be determined by the ability of that galaxy to channel digestible fuel (i.e., gas) to the smallest scales. Large stellar bars, as well as tidal interactions and mergers, can drive gas efficiently from the outer disk into the inner kpc (Shlosman, Frank, & Begelman 1989; Shlosman, Begelman & Frank 1990), but it is non-trivial to drive gas to smaller scales. Nuclear (secondary) bars nested within the large-scale (primary) stellar bar (e.g., Shlosman et al. 1989; Laine et al. 2002) have been suggested as vehicles which drive gas efficiently to scales of 10–100 pc.

We will concentrate here on observational evidence, mostly statistical in nature, of the effects of bars and interactions on starburst and Seyfert activity, which are conceivably linked to these facilitators of inflow. After reviewing observations which can support the theoretical expectation that bars will concentrate mass in the center of a galaxy (Sect. 2), we will review separately the observational evidence, or lack thereof, for relationships between the forms of non-axisymmetry and activity identified above (Sect. 3-6). We will then discuss nuclear rings of star formation and their relations with bars and nuclear activity (Sect. 7, 8). Concluding remarks are given in Sect. 9.

2. Bars and central mass concentration

There are several pieces of observational evidence which indicate that bars do indeed concentrate gas in the central regions of spiral galaxies, as expected theoretically and numerically. We will briefly review the evidence here, but also emphasize that it does not necessarily imply that the mass concentration stimulated by bars is connected directly to the occurrence or fueling of nuclear activity because the scales involved are different. Such a connection between mass concentration and activity would have to be separately studied in a statistically meaningful way, which has to our knowledge not been done to date.

The most comprehensive evidence so far for mass concentration by bars stems from surveys of molecular gas concentration in barred as compared to non-barred galaxies, traced through emission in the millimeter domain by CO molecules. Sakamoto et al. (1999) used data from the Owens Valley and Nobeyama interferometers for 10 barred and 10 non-barred galaxies, and found that the barred galaxies, statistically, have more concentrated CO emission, and thus, presumably, molecular hydrogen. More recently, Sheth et al. (2004) used the data from the BIMA-SONG survey (Regan et al. 2001; Helfer et al. 2003) to confirm this conclusion. Their sample contains 29 barred and 15 non-barred galaxies of types Sab-Sd, which have comparable molecular gas masses and surface densities across their disks. In the central kiloparsec, however, both the average surface density and the central concentration of molecular gas are about three times higher in the barred than in the non-barred galaxies, effects which are somewhat more pronounced in the early than in the late type galaxies in the sample. Although the galaxies with the most centrally concentrated CO emission and the highest surface densities in the central kiloparsec are barred, the scatter is large. One of the caveats in this kind of work is the value of the conversion factor between CO intensity and molecular hydrogen column density, the X-factor, which is usually assumed constant. Findings such as the one by Hüttemeister et al. (2000) of significant changes in the conversion factor within the barred galaxy NGC 7479 as determined from $^{12}CO/^{13}CO$ line intensity ratios, possibly related to the gas being more diffuse, or unbound, in the bar, may not invalidate this general assumption, but do highlight the need for more detailed scrutiny.

Maiolino, Risaliti, & Salvati (1999) studied the atomic gas column density in front of Seyfert nuclei using X-ray measurements, and found significantly higher columns in those Seyferts which are in barred hosts than in those in non-barred galaxies. Alonso-Herrero & Knapen (2001) studied H II region populations in the central regions of spiral galaxies, and found that both the luminosity of the most luminous H II regions and the massive star formation efficiency are higher in the barred than in the non-barred galaxies, which again was interpreted as a consequence of enhanced gas concentration by bars. There is thus indeed some observational evidence that bars drive gas towards the nuclear zones of galaxies. Below, we will explore whether this can be related to the occurrence of nuclear starburst or Seyfert activity.

3. Bars and starburst activity

Clear indications that nuclear starbursts preferentially occur in barred hosts have been reported since the early eighties, from radio continuum (e.g., Hummel 1981; Puxley, Hawarden, & Mountain 1988; Huang et al. 1996) or infrared (e.g., Hawarden et al. 1986; Devereux 1987; Dressel 1988) emission and its distribution, or from the morphology of spectroscopically selected starburst galaxies (Arsenault 1989). Even though the results are not unambiguous (see, e.g., discussions in Huang et al. 1996), there is a clear trend. For example, Hummel (1981) found that the central radio continuum component is typically twice as strong in barred than in non-barred galaxies; Hawarden et al. (1986) found that basically all galaxies with a high $25/12\mu$m flux ratio are barred; and Arsenault (1989) found an enhanced bar+ring fraction among starburst hosts. Huang et al. (1996) refined the methodology used in earlier papers and used IRAS data to confirm that starburst hosts are preferentially barred. They do point out, however, that this result only holds for strong bars (SB class in the RC3 catalog, de Vaucouleurs et al. 1991) and in early-type galaxies. All results mentioned above are based on morphological classifications taken from catalogs such as the RC3.

A study of the molecular gas properties in the inner kpc of starbursts and non-starbursts (Jogee 2001; Jogee et al. 2001) shows that the starbursts generally host larger central gas densities (assuming a standard X-factor). The fact that both starbursts and non-starbursts in Jogee's sample can host a large-scale bar suggests that the lifetime of the starburst is short with respect to the timescale over which bars evolve or dissolve. The data also suggest that in a given barred galaxy the dominant star formation mode can change from an inefficient pre-burst phase in the early stages into a powerful circumnuclear starburst once a high enough central gas density builds up. These findings are consistent with the reports referred to above that starbursts are more common in barred than in unbarred galaxies, but they also imply that the presence of a bar is not a sufficient condition for a concurrent starburst.

We conclude that statistical studies show that bars and starbursts are connected, but that the results are subject to important caveats and exclusions. Further study is needed, using carefully defined samples, and exploring more direct starburst indicators, such as nuclear spectra, Hα imaging, or possibly careful SED fitting, all combined with a bar analysis based upon, ideally, near-infrared (NIR) imaging. What also needs more scrutiny is the nature of the starburst associated with a bar. Hawarden et al. (1986) already suggested that these starbursts might be circumnuclear, and we now know that such circumnuclear star formation can be very compact (e.g., González Delgado et al. 1998). Given the theoretically *and* observationally established strong connections between circumnuclear star formation and non-axisymmetry in the gravitational potential of their host galaxy (Sect. 7), and given the importance of such features for our understanding of galaxy dynamics and evolution, *HST* imaging ought to be employed to investigate whether bar-related starburst activity is circumnuclear rather than nuclear in general.

4. Bars and Seyfert activity

Seyfert galaxies have a number of characteristics which make them particularly suitable for a study of their host galaxies: they are relatively local AGN and occur predominantly in disk galaxies. Over the years, and starting with the work of Adams (1977), a fair number of authors have studied the fraction of bars in Seyfert galaxies, often comparing the results for the AGN with those for a control sample (e.g., Adams 1977; Simkin, Su, & Schwarz 1980; Balick & Heckman 1982; MacKenty 1990). Unfortunately, these early surveys, and many of the later ones (e.g., Moles, Márquez, & Pérez 1995; Ho, Filippenko & Sargent 1997b; Crenshaw, Kraemer, & Gabel 2003) suffer from one or more of the following imperfections: they are based on optical imaging, where stellar bars are much more difficult to detect than in the NIR; they use the RC3 classification or, worse, ad-hoc and non-reproducible classification criteria to determine whether a galaxy is barred; or they suffer from the absence of properly matched control samples.

There have also been a small number of studies using new, high-quality, NIR imaging of well-matched samples of Seyfert and quiescent galaxies. Mulchaey & Regan (1997), from one such study, report identical bar fractions, but Knapen, Shlosman, & Peletier (2000), using imaging at higher spatial resolution and a rigorously applied set of bar criteria, find a marginally significant difference, with a higher bar fraction in a sample of CfA Seyferts than in a control sample of non-Seyferts (approximately 80% vs. 60%).

This difference was later confirmed at a 2.5 σ level by Laine et al. (2002), who improved upon the work by Knapen et al. (2000) by increasing the sample size (112 instead of 58 galaxies in total) and by using high resolution *HST* NICMOS NIR images of the central regions of all galaxies. Laine et al. (2002) find that 41 of their 56 Seyfert galaxies have at least one bar (73%±6%, where the uncertainty is the Poisson error due primarily to the sample size), against 28 of the 56 non-Seyfert control galaxies (50%±7%). Another result is that almost one of every five sample galaxies, and almost one of every three barred galaxies, have more than one bar, although the fraction of small, or nuclear, bars is not enhanced in Seyfert galaxies (see also Erwin & Sparke 2002, who reach much the same conclusions on nuclear bars, even though the classification of especially the smallest bars remains a matter of debate for some individual galaxies, see, e.g., Laine et al. 2002; Erwin 2004). Laine et al. also find that there is no correlation between the presence of companion galaxies, even relatively bright ones, and a bar, thus refuting a claim by Márquez et al. (2000) that the results by Knapen et al. (2000) were unreliable because not all the sample galaxies were isolated.

We can thus conclude that carefully performed studies show that there is a slight, though only just about significant, excess of bars among Seyfert galaxies as compared to non-Seyfert control samples. A significant fraction of Seyfert galaxies appear to be non-barred, although future analysis could potentially reveal a weak or very small bar, or another form of non-axisymmetry in their gravitational potential which could have similar dynamical effects (Shlosman et al. 1989). What even the most detailed of these studies have not shown, however, is a one-to-one correlation between bars and Seyfert activity. Given that any fueling process must be accompanied by angular momentum loss, which in turn is most likely induced by non-axisymmetries, either the timescales of bars (or interactions, see below) are different from those of the activity, or the non-axisymmetries are not as easy to measure as we think, for instance because they occur at smaller scales, or are masqueraded to a significant extent by, e.g., dust or star formation (Laine et al. 2002).

5. Interactions and starburst activity

There is ample anecdotal evidence for the connection between galaxy interactions and starburst activity. Practically all extreme infrared sources, specifically the Ultra-Luminous InfraRed Galaxies (ULIRGs), which are thought to be powered mainly by extreme starbursts (Genzel et al. 1998), occur in galaxies with disturbed morphologies, presumably interacting (e.g., Joseph & Wright 1985; Armus, Heckman, & Miley 1987; Sanders et al. 1988; Clements et al. 1996; Murphy et al. 1996; Sanders & Mirabel 1996; see also Sanders, these proceedings, p. 000). Partly as a result of this finding, and considering the much increased interaction rates at large lookback times expected from cosmological models, a significant occurrence of massive starbursts, mostly dust-obscured and thus hidden from direct view, is sometimes inferred from the observation of so-called SCUBA-sources (e.g., Smail, Ivison, & Blain 1997). Given the evidence from, for instance, observations of ULIRGs, it is perhaps not unreasonable to state that such massive starbursts are powered in galaxies which are undergoing a major upheaval, i.e., are merging or interacting.

More in general though, the picture is far less clear, as nicely illustrated in a recent paper by Bergvall, Laurikainen, & Aalto (2003). These authors considered two matched samples of nearby interacting (pairs and clear cases of mergers) and non-interacting galaxies, and measured star formation indices based on *UBV* colors. Contrary to previous reports in the literature (notably by Larson & Tinsley 1978), Bergvall et al. do not find significantly enhanced star-forming activity among the interacting/merging galaxies. Bergvall et al. (2003) estimate from their sample that only about 0.1% of a magnitude limited sample of galaxies will be massive starbursts generated by interactions and mergers. The authors then argue that since virtually all ULIRG morphologies show evidence for recent mergers, other mechanisms cannot reasonably be expected to trigger massive starbursts. Although Bergvall et al.'s fraction of 0.1% is based upon one true massive starburst (ESO 286-IG19) found in a sample of 59 and thus carries substantial error bars, it is also clear that such massive starbursts are a very rare occurrence indeed, at least, but possibly not exclusively (Bergvall et al.), in the local universe.

So although mergers can undoubtedly lead to massive starbursts, and most extreme starbursts show evidence for a merging/interacting history, they appear to do so only in exceptionally rare cases. Most interactions between galaxies may not lead to any increase in the starburst activity, and those that do may be selected cases where a set of parameters, both internal to the galaxies and regarding the orbital geometry of the merger, is conducive to the occurrence of starburst activity (e.g., Mihos & Hernquist 1996). Laine et al. (2003) find very little evidence for trends in starburst activity from detailed *HST* imaging of the Toomre sequence of merging galaxies, further illustrating this point.

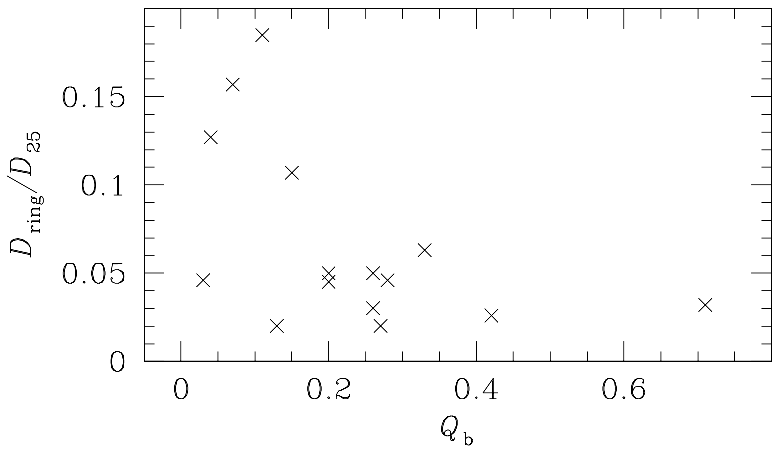

Figure 1. Relative size (ring diameter divided by host galaxy diameter) for a sample of 15 nuclear rings as a function of the gravitational torque Q_b, or strength, of the bar of its host galaxy. Data from Knapen, Pérez-Ramírez, & Laine (2002) and Knapen (2004).

6. Interactions and Seyfert activity

Galaxy interactions can easily lead to non-axisymmetries in the gravitational potential of one or more of the galaxies involved, and as such can be implicated in angular momentum loss of inflowing material, and thus conceivably in AGN fueling (Shlosman et al. 1989). Although indeed Seyfert activity occurs in interacting and merging galaxies (NGC 2992 is a rather spectacular example), no unambiguous evidence has been reported for an excess of the numbers of companions to Seyfert galaxies as compared to non-active control galaxies (e.g., Fuentes-Williams & Stocke 1988; de Robertis, Yee, & Hayhoe 1998), nor for a different incidence of Seyfert or AGN activity among more or less crowded environments (e.g., Kelm, Focardi, & Palumbo 1998; Miller et al. 2003). Much of the earlier work, some of which claimed a statistical connection between interactions and Seyfert activity, was unfortunately plagued by poor control sample selection (see Laurikainen & Salo 1995 for a detailed review), while most studies, including some of the most recent ones, are not based on complete sets of redshift information for the possible companion galaxies. In addition, Laine et al. (2002) have shown that the bar fraction among both their Seyfert and non-Seyfert sample galaxies is completely independent of the presence of faint, or bright, companions (interacting galaxies were not considered by Laine et al.). We thus conclude that interactions and Seyfert activity may well be linked in individual cases, but that as yet the case that they are statistically connected has not been made convincingly.

7. Bars and nuclear rings

As discussed earlier in this paper, bars concentrate gas in the central regions of galaxies. Bars, however, also set up resonances which can act as focal points for the gas flow, and where gas concentrates in limited radial ranges (see, e.g., review by Shlosman 1999). Rings in disk galaxies are intimately linked to the internal dynamics and the evolution of their hosts, are relatively common, and are most often outlined by massive star formation (see Buta & Combes 1996 for a comprehensive review on galactic rings).

Nuclear rings, on scales of less than one to roughly two kiloparsec in radius, occur in one of every five spiral galaxies (Knapen 2004). They are found almost exclusively in barred galaxies (e.g., Buta & Combes 1996; Knapen 2004; see below), and can be directly linked to inner Lindblad resonances (Knapen et al. 1995; Heller & Shlosman 1996; Shlosman 1999). Individual gas clouds within such a ring can become gravitationally unstable, either spontaneously (Elmegreen 1994), or under the influence of density waves set up by the bar (Knapen et al. 1995; Ryder, Knapen, & Takamiya 2001), and rings are well known for the significant massive star formation occurring within them (although rings without star formation occur as well, see, e.g., Shlosman 1999; Erwin & Sparke 2002). Because of the much enhanced massive star formation occurring in nuclear rings, they are prime tracers of star formation processes in starburst regions, as well as of the dynamics of galaxies on scales of a kiloparsec from the nucleus. As an example of the latter, Fig. 1 shows the relation between the relative nuclear ring size and the gravitational bar torque (a measure of the strength of the bar) for 15 nuclear rings. It is clear that large rings can only occur in weak bars, a result which confirms expectations from theory and modeling, in which, simply put, the extent of the perpendicular $x2$ orbits needed to sustain the nuclear ring is limited as the bar gets stronger, i.e., as the $x1$ orbits become more elongated (see Knapen et al. 1995; Heller & Shlosman 1996; Knapen, Pérez-Ramírez, & Laine 2002; Knapen 2004).

Some rings apparently occur in non-barred galaxies. In some cases, the host may be classified as non-barred in the major catalogs, but a small bar shows up clearly in NIR imaging (for instance, NGC 1068, Scoville et al. 1988, and NGC 4725, Shaw et al. 1993; Möllenhoff, Matthias, & Gerhard 1995; see the more elaborate discussion in Knapen 2004). Other apparently non-barred nuclear ring hosts may either have a weak oval distortion, or be undergoing the effects of an interaction with a companion galaxy. In either case, a departure from axisymmetry would be set up in the gravitational potential of the galaxy which could lead to ring formation in a very similar way to when a bar is present (Shlosman et al. 1989). We give two examples from the recent literature.

The first example is that of NGC 278, a small, nearby and isolated spiral galaxy ($v_{\rm sys} = 640\,{\rm km\,s^{-1}}$; $M_B = -18.8$) recently observed in optical and H I by Knapen et al. (2004a). Although classified as SAB(rs)b in the RC3, there is no evidence for the presence of a bar in this galaxy from either *HST* WFPC2 or ground-based NIR imaging.

As seen in Fig. 2 (*left*), a $B-R$ color index image of NGC 278, its optical disk shows two distinct regions, the inner one with copious star formation and clear spiral arm structure, and the outer one ($r > 27$ arcsec or 1.5 kpc) which is almost completely featureless, of low surface brightness, and rather red. The H I disk (shown at a low resolution of 120 arcsec in Fig 2, *right*) is much more extended than the optical disk (indicated by the white circle in the H I figure) and shows both morphological (Fig. 2) and kinematic (Knapen et al. 2004a)

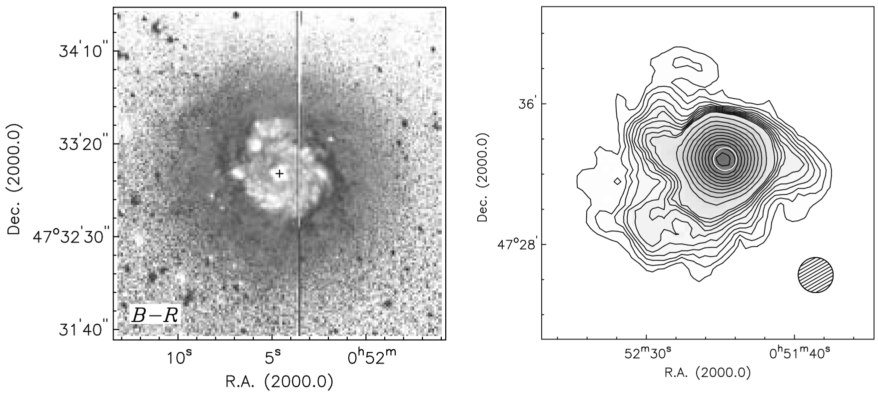

Figure 2. $B-R$ (*left*) and H I (*right*) views of the galaxy NGC 278. The scales covered in the two panels are very different: the total extent of the optical disk of the galaxy, more or less twice the area shown on the *left*, is indicated by the small white circle in the middle of the *right* panel. The $B-R$ color index image shows bluer colors as lighter shades. The H I image shows the integrated H I surface density distribution at 120 arcsec resolution, with contour levels at $(1,2,3,...,9)\times 10^{19}, (1,1.5,2,...,6.5)\times 10^{20}\,\mathrm{cm}^{-2}$. The vertical spike in the $B-R$ image is an artifact. Data from Knapen et al. (2004a).

disturbances which suggest a recent minor merger with a small gas-rich galaxy, perhaps similar to a Magellanic cloud.

The scale and morphology of the region of star formation in NGC 278 indicate that this is in fact a nuclear ring, albeit one with a much larger *relative* size with respect to its host galaxy than practically all other known nuclear rings (the absolute radius of the nuclear ring is about a kiloparsec, normal for nuclear rings). Knapen et al. (2004a) postulate that it is in fact the past interaction which has set up a non-axisymmetry in the gravitational potential, which in turn, in a way very similar to the action of a classic bar, leads to the formation of the nuclear ring. The case of NGC 278 illustrates how in apparently non-barred galaxies rings can be caused by departures from axisymmetry induced by interactions, but also shows how difficult it can be to uncover this: in the case of NGC 278 only through detailed H I observations.

Another example of the same class may be the case of the blue compact dwarf galaxy Mrk 409, which has recently been shown to possess two star-forming rings, a nuclear one at 0.5 kpc radius, and a further one at a radius of some 2 kpc (Gil de Paz et al. 2003). These authors interpret the inner of the two rings as resulting from a starburst-driven shock interacting with the interstellar medium. In such a scenario, the nuclear starburst would sweep up gas in the galactic plane, which would eventually reach densities high enough for it to become molecular, followed by a phase of massive star formation. Such a scenario seems unattractive, by the way, as a general one, because it would depend on a very strong starburst-bar correlation to reproduce the observed very strong nuclear ring-bar correlation (the former has not been established nearly as conclusively as the latter, see Sect. 3). Gil de Paz et al. (2003) do not offer a preferred explanation for the outermost of the two observed rings in this galaxy.

In light of the appearance and scales of the two rings in Mrk 409, it is tempting to consider them as resonance rings. In that case, as in host galaxies of other nuclear rings, we would expect to see some evidence for the presence of a non-axisymmetry in the gravitational potential. Also known as NGC 3011, Mrk 409 has been classified as '.L.....' in the RC3. No *HST* images are available from the archive, and a 2MASS (Jarrett et al. 2003) image shows no evidence for a bar. We checked the Hyperleda database (Paturel et al. 2003), and found a number of companion galaxies which, although probably not directly interacting, are certainly close enough to be, or to have been, in some kind of gravitational partnership with Mrk 409. These include PGC 028169 with $v_{\rm sys} = 1557\,{\rm km\,s^{-1}}$ and at a distance of less than 250 kpc, UGC 5287 ($v_{\rm sys} = 1470\,{\rm km\,s^{-1}}$; $250 < d < 300$ kpc), and UGC 5282 ($v_{\rm sys} = 1470\,{\rm km\,s^{-1}}$; $300 < d < 350$ kpc). All these galaxies have similar magnitudes to Mrk 409, which has a $v_{\rm sys}$ of $1527\,{\rm km\,s^{-1}}$. So there are clearly companion galaxies around which may have caused non-axisymmetry in the potential, possibly as in NGC 278. Unfortunately, H I data are not available in this case, but we speculate that these might well show disturbed kinematics and morphology in the outer regions.

8. Nuclear rings and nuclear activity

Although nuclear rings and especially nuclear activity have as separate topics received considerable attention in the literature, their possible interrelation has not been much studied. Many nuclear rings, of course, are anecdotally known to occur in galaxies which also host a nuclear starburst or a prominent AGN (often of Seyfert or LINER type, given the typical parameters of the host galaxies involved), and some famous examples include NGC 1068 and NGC 4303.

In a recent paper, we explored the correlations between nuclear activity (both of the non-stellar and starburst variety) and the occurrence of nuclear rings in a sample of 57 nearby spiral galaxies (Knapen 2004). Using information on the activity from the NASA/IPAC Extragalactic Database (NED) and ring parameters from our own Hα imaging survey (Knapen et al. 2004b), we found not only that nuclear rings significantly more often than not occur in galaxies which also host nuclear activity (only two of the 12 nuclear rings occur in a galaxy which is neither a starburst nor an AGN host; 30 of the 57 sample galaxies would fall into this category), but also that the circumnuclear Hα emission morphology of the AGN and starbursts is significantly more often in the form of a ring than in non-AGN, non-starburst galaxies (38% of AGN, 33% of starbursts, 11% of non-AGN, and 7% of non-AGN non-starburst galaxies have circumnuclear rings in our sample of galaxies).

Although the number of galaxies in this initial study is rather small for detailed statistical analyses, we did find this most interesting correlation between the occurrence of nuclear rings and that of nuclear activity. Our initial interpretation of this effect is that both nuclear rings, as traced by the massive star formation within them, and starbursts and AGN (of the Seyfert or LINER variety) trace very recent gas inflow. Although it is not clear *a priori* why the kpc-scale fueling of nuclear rings and the pc-scale fueling of activity might be so closely related, nuclear rings do seem to show a potential for being very interesting and direct tracers of AGN fueling. These findings may also be related to the reported higher incidence of rings (inner and outer, as based on RC3 classifications) among Seyfert and LINER hosts than among normal or starburst galaxies (Hunt & Malkan 1999). All these aspects of rings and nuclear activity need further scrutiny.

9. Concluding remarks

There is significant evidence that bars can drive gaseous material to the central regions of a galaxy (Sect. 2), but it is hard to pin down the evidence that this gas leads directly to AGN or even starburst activity. There are indications that starbursts are provoked by bars or interactions, though most probably not in general, but only in special cases (Sect. 3, 5). For Seyfert galaxies, there is very little evidence indeed that this kind of AGN preferentially occurs in host galaxies which are either barred (Sect. 4) or interacting (Sect. 6). These rather disappointing observational results, however, do not imply that bars and interactions can be declared altogether innocent of being involved with nuclear activity.

The kind of deviations from axisymmetry in the gravitational potential of the host galaxy set up by bars and interactions has, theoretically and numerically, long since been linked to nuclear activity (e.g., Shlosman et al. 1989, 1990; see also review by Shlosman 2003). Shlosman et al. postulated that the presence of such non-axisymmetry would be a necessary, but not sufficient condition for the onset of nuclear activity, and that an additional factor or factors, such as the availability of gas at the relevant (small) scales, would likely play a role.

Observationally, we now know that bars can lead to central gas concentration, thus assuring that a viable gas reservoir is present within the central kiloparsec. Either many (or most, or possibly even all) galaxies then become a starburst or Seyfert-type AGN at some stage, but for a short time (and possibly eradicating any links we may wish to find with the host's properties; Beckman 2001), or some mechanism, as yet unidentified observationally, turns on the activity in specific galaxies. This mechanism may well include gravitational torques due to a non-axisymmetric matter distribution, for instance due to nuclear bars (e.g., Laine et al. 2002), which can dump fuel very close to the nucleus indeed (Shlosman et al. 1989). The timescales of such nuclear inflow are unknown, but may be very short.

Nuclear bars are, unfortunately, rather hard to study observationally. Morphological studies based upon, e.g., *HST* NIR imaging are hampered by the effects of dust extinction and star formation (Laine et al. 2002). The morphology of dust lanes in the central kpc has been connected to attempts to identify nuclear bars (Regan & Mulchaey 1999; Martini et al. 2001), but nuclear bars, unlike large bars, cannot be expected to lead to a well-defined morphology of offset dust lanes (Shlosman & Heller 2002; Maciejewski et al. 2002). A possible way forward here is the use of integral field spectroscopy (e.g., Bacon et al. 2001), which, if used in conjunction with adaptive optics techniques, gives simultaneous high-resolution mapping of the distributions of stellar populations and dust, as well as of the gas and stellar kinematics. In combination with detailed numerical modeling, this could lead to the detection of the dynamical effects of a nuclear bar on gas flows which may be directly related to the fueling process of starbursts and/or AGN.

As indicated by the many, often contradictory, studies referenced in this paper, there is, however, also still a dire need for continued study of the detailed properties of large and well-defined samples of AGN and starburst host galaxies, as well as of carefully matched control samples of non-active galaxies. Tantalising new results, briefly described in Sect. 7 and 8, indicate that nuclear rings ought to be included in such investigations. The current or future availability of datasets of unprecedented scope and size (e.g., the 2MASS or Sloan surveys) must be exploited to identify and analyse any relationships between nuclear activity and the properties of their host galaxies, which are no doubt more subtle than often suggested in the past.

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