The Starburst-AGN Connection

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Abstract. The issue of a starburst-AGN connection in local and distant galaxies is relevant for understanding galaxy formation and evolution, the star formation and metal enrichment history of the universe, the origin of the extragalactic background at low and high energies, and the origin of nuclear activity in galaxies. Here I review some of the observational evidence recently brought forward in favor of a connection between the starburst and AGN phenomena. I conclude by raising a number of questions concerning the exact nature of this connection.

1 Introduction

Since the focus of this conference is the starburst phenomenon, many of us would rather “sweep AGN activity under the rug” and only consider star formation. This would be a mistake! There is growing evidence that intense star formation and nuclear activity often come hand in hand. The apparent correlation between the mass of dormant black holes at the centers of nearby galaxies and the mass of their spheroids (e.g., Kormendy & Richstone 1995; Faber et al. 1997; Magorrian et al. 1998; Gebhardt et al. 2000) suggests a direct link between the formation of spheroids and the growth of central black holes. Since a starburst is a natural consequence of the dissipative gaseous processes associated with spheroid formation (e.g., Barnes & Hernquist 1991; Kormendy & Sanders 1992; Mihos & Hernquist 1994), a starburst-AGN connection dating back to the early universe is implied by these results. Closer to us, the presence of circumnuclear starbursts in an increasing number of local AGNs (discussed in more detail in §2) also suggests a connection between the starburst and AGN phenomena.

This possible starburst-AGN connection has direct bearings on our understanding of the early universe. A large contribution from unsuspected (hidden) AGNs would complicate the deduction of the star formation history of the universe from galaxy luminosity functions (e.g., Blain et al. 1999). This in turn may change our current views on the history of metal enrichment and the importance of feedback processes in the early universe (e.g., Franx et al. 1997; Pettini et al. 2000; Ferrara & Tolstoy 2000). Similarly, a correction needs to be applied to account for obscured AGNs as contributors to the far-infrared extragalactic background. Recent X-ray observations with Chandra have added substantially to the debate. The discovery that some fraction of the X-ray background appears to be produced by a population of heavily obscured AGNs (e.g., Mushotzky et al. 2000; Barger et al. 2000), objects which have been largely missed in optical...
surveys due to extremely heavy obscuration, has clearly further increased the importance of studies of the starburst-AGN connection in distant infrared-selected galaxies.

The rest of this paper is organized as follows. In §2, I discuss recent (< 5 years approx.) results which appear to favor a starburst-AGN connection. This discussion is not meant to be a exhaustive (or even impartial) review of the recent literature on this subject; it is only meant to illustrate some of the best cases where a starburst-AGN connection indeed appears to exist. In the last section (§3), I raise several questions regarding the nature of this starburst-AGN connection.

2 Evidence for a Starburst-AGN Connection

Since the triggering mechanism for AGN activity probably depends on the luminosity of the AGN, I make a distinction in the following discussion between the nearby, low-luminosity Seyferts and Fanaroff-Riley type I (FR I) radio galaxies and the more distant and powerful quasars, Fanaroff-Riley type II (FR II) radio galaxies, and ultraluminous infrared galaxies (ULIRGs; \( \log \left[ L_{\text{IR}}/L_\odot \right] \geq 12 \) by definition).

2.1 Low-Luminosity Regime: Seyferts, FR I radio galaxies

The fueling of AGNs requires mass accretion rates \( \frac{dM}{dt} \approx 1.7 \left( \frac{0.1}{\epsilon} \right) \left( \frac{L}{10^{46} \text{ erg s}^{-1}} \right) M_\odot \text{ yr}^{-1} \), where \( \epsilon \) is the mass-to-energy conversion efficiency. A modest accretion rate of order \( \sim 0.01 M_\odot \text{ yr}^{-1} \) is therefore sufficient to power a Seyfert galaxy like NGC 1068. Only a small fraction of the total gas content of a typical host galaxy is therefore necessary for the fueling of these low-luminosity AGNs. A broad range of mechanisms including intrinsic processes (e.g., stellar winds and collisions; dynamical friction of giant molecular clouds against stars; nuclear bars or spirals produced by gravitational instabilities in the disk) and external processes (e.g., “minor” galaxy interactions or mergers) may be at work in these objects. While a detailed discussion of these processes is beyond the scope of the present paper (see Combes 2000 for a recent review of the subject), suffice it to say that there is little or no observational evidence for Seyfert nuclei to occur preferentially in barred systems (e.g., McLeod & Rieke 1995; Heraudeau et al. 1996; Mulchaey & Regan 1997; Ho, Filippenko, & Sargent 1997) or to have recently experienced a major interaction or merger (Fuentes-Williams & Stocke 1988; Dultzin-Hacyan 1998; De Robertis, Yee, & Hayhoe 1998; Virani, de Robertis, & Van Dalsen 2000; although see last paragraph of this subsection). These results seem to favor minor intrinsic processes over large-scale external processes for the fueling of low-luminosity AGNs. Ejecta from a nuclear star cluster (e.g., Norman & Scoville 1988; Petty 1992; Williams, Baker, & Perry 1999) may be all that is needed in the cases of Seyferts and other low-luminosity AGNs to keep their nuclei active. The “angular momentum problem” in feeding low-luminosity AGNs may therefore reduce to forming the dense stellar cluster...
in the first place. Nuclear starbursts are the prime candidates for the formation of these clusters.

Several studies have shown that the molecular material needed to fuel nuclear starbursts in Seyfert galaxies is present near the nuclei of these objects (e.g., Meixner et al. 1990; Tacconi et al. 1997; Kohno et al. 1998; Baker & Scoville 1998). But is this material forming stars? Direct evidence for recent nuclear star formation now exists in a number of Seyfert 2 galaxies (i.e. Seyferts without broad recombination lines). Optical and ultraviolet spectroscopy of the nuclear regions of these galaxies often reveals the signatures of young and intermediate-age stars. The stellar Ca II triplet feature at $\lambda\lambda 8498, 8542, 8662$ in Seyfert 2s has an equivalent width similar to that in normal galaxies while the stellar Mg I $\lambda 5175$ is often weaker (Terlevich, Diaz, & Terlevich 1990). This result is difficult to explain with a combination of an old stellar population and a featureless power-law continuum from an AGN. The most natural explanation is that young red supergiants contribute significantly to the continuum from the central regions. Evidence for intermediate-age (a few 100 Myrs) stars in these galaxies is also apparent in the blue part of the spectrum, where the high-order Balmer series and He I absorption lines appear to be present in more than half of the brightest Seyfert 2 galaxies (e.g., Cid Fernandes & Terlevich 1995; González Delgado, Heckman, & Leitherer 2001). A few of these objects may even harbor a broad emission feature near 4680 Å, possibly the signature of a population of young (a few Myrs) Wolf-Rayet stars (González Delgado et al. 2001). The ultraviolet continuum from some of the brightest UV Seyfert 2s also appears to be dominated by young stars based on the strength of absorption features typically formed in the photospheres and in the stellar winds of massive stars (e.g., Heckman et al. 1997; González Delgado et al. 1998). The extended, soft, thermal X-ray emission from these objects seems to confirm these results (Levenson, Weaver, & Heckman 2001). The bolometric luminosities of these nuclear starbursts ($\sim 10^{10} L_\odot$) are similar to the estimated bolometric luminosities of their obscured Seyfert 1 nuclei.

Interestingly, a distinction appears to exist between Seyfert 1s and Seyfert 2s. Seyfert 2 galaxies have long been known to present a larger far- and mid-infrared excess than Seyfert 1s (e.g., Rodriguez-Espinosa, Rudy, & Jones 1986; Dultzin-Hacyan et al. 1988; Pier & Krolik 1993; Maiolino et al. 1995), but most of this excess emission may be attributed to star formation in the host galaxy rather than from a nuclear starburst. The departure of the galaxy or bulge blue luminosity of Seyfert 2s from the Tully-Fisher and Faber-Jackson relationships (e.g., Whittle et al. 1992a, 1992b; Nelson & Whittle 1995) and the diffuse radio emission around some Seyfert nuclei (Wilson 1988) may have the same origin. However, recent investigations have also suggested excess nuclear starburst activity in Seyfert 2s relative to Seyfert 1s (González Delgado et al. 2001; Gu et al. 2001) and possibly a higher frequency of companions near type 2 objects (e.g., De Robertis et al. 1999; Dultzin-Hacyan et al. 1999; Levenson, Weaver, & Heckman 2001). These results cannot be explained in the context of the Seyfert unification theory (which purports that Seyfert 1s and 2s are basically the same type of
objects seen from different perspectives), but they may reflect an evolutionary connection between starbursts, Seyfert 2s, and Seyfert 1s.

2.2 High-Luminosity Regime: QSOs, FR II Radio Galaxies, ULIRGs

The stringent requirements on the mass accretion rates for luminous AGNs almost certainly require external processes such as “major” galaxy interactions or mergers to be involved in triggering and sustaining this high level of activity over \( \sim 10^8 \) years. Substantial evidence exists that the precursors to at least some powerful AGNs have indeed been gas-rich mergers. Classical double (FR II) radio galaxies have long been known to show tidal tails and other signs of interaction (Smith & Heckman 1989; Baum, Heckman, & van Breugel 1992). Evidence for recent or on-going galactic interactions is also seen in several quasars (e.g., Hutchings et al. 1994; Bahcall et al. 1997; Boyle et al. 1998). Abundant molecular gas has been detected in radio galaxies and quasars (e.g., Sanders et al. 1988b, 1989b; Barvainis et al. 1989, 1995; Mirabel, Sanders, & Kazés 1989; Scoville et al. 1993; Ohta et al. 1996; Omont et al. 1996; Evans et al. 1999a,b), and many of them also show the spectroscopic signatures of recent star formation (e.g., Tadhunter, Dickson, & Shaw 1996; Tran et al. 1999; Brotherton et al. 1999). The far-infrared excess in some of these objects may also be attributed to star formation (e.g., Rowan-Robinson 1995; see Sanders et al. 1989a for another interpretation). In this merger scenario, quasars were more common in the past because of the enhanced frequency of collisions \( \propto (1+z)^{4.0\pm2.5} \); e.g., Zepf & Koo 1989] and the larger proportion of unprocessed gas. Moreover, the observed redshift cut-off for quasars \( z \approx 5 \) marks the epoch at which disk systems formed.

ULIRGs may provide the clearest observational link between galaxy mergers, starbursts and powerful AGNs. Nearly all ULIGs show strong signs of advanced tidal interactions (e.g., Sanders et al. 1988a; Melnick & Mirabel 1990; Murphy et al. 1996; Clements et al. 1996). All of them are very rich in molecular gas (e.g., Solomon et al. 1997; Frayer et al. 1998, 1999), most of which is distributed well within the inner kpc of the galaxy (e.g., Downes & Solomon 1998; Bryant & Scoville 1999; Sakamoto et al. 1999). They also present a large concentration of activity in their nuclei, including strong optical emission lines characteristic of a starbursting stellar population and in about 30% of cases, broad or high-ionization emission lines that suggest the presence of a powerful AGN coexisting with the starburst (e.g., Kim et al. 1998; Wu et al. 1998a,b; Veilleux et al. 1995, 1999a; Kewley et al. 2001). Similar results are found in the near-infrared (e.g., Goldader et al. 1995, 1997; Veilleux et al. 1997, 1999b) and in the mid-infrared (e.g., Genzel et al. 1998; Lutz et al. 1998; Rigopoulou et al. 1999; Lutz, Veilleux, & Genzel 1999; Dudley 1999).

The fraction of AGN-dominated ULIRGs is significantly larger among objects with high infrared luminosities and warm infrared colors (e.g., Kim et al. 1998; Veilleux et al. 1995, 1999a,b; Wu et al. 1998b; Kewley et al. 2001). Current results on a limited set of ULIRGs (e.g., Rigopoulou et al. 1999) suggest that
the dominance of AGN or starburst in ULIRGs may depend on local and short-
term conditions (e.g., compression of the circumnuclear interstellar medium as a
function of gas content and galaxy structure, local accretion rate onto the central
black hole, etc.) in addition to the global state of the merger. Still several lines
of evidence suggest that warm ULIRGs are indeed more advanced, transition
objects and that (radio quiet) QSOs correspond to the final state of the merger-
induced sequence “starburst → ULIRGs → QSOs” (e.g., Surace & Sanders 1999;
Scoville et al. 2000; Zheng et al. 1999; Veilleux et al. 2001).

3 Unanswered Questions

The exact nature of this starburst-AGN connection is not at all clear. Unan-
swered questions include:

1. Can an AGN be triggered without a burst of star formation?
2. If a SMBH is indeed present in every (massive) galaxy, can a starburst be
taking place without any AGN activity?
3. Can starbursts and AGNs simply coexist without interacting with each
other?
4. If not, in what way are the starbursts and AGNs interacting?
   – Is mass loss from the central stellar cluster fueling (low-luminosity) AGNs?
   – Is the molecular gas “unused” by the starburst feeding the SMBH?
5. Is there an evolutionary connection between starbursts and AGNs?
   – Which of the starburst or AGN comes first?
   – Is the merger-induced starburst → QSO model correct?
   – Is there a similar sequence in low-luminosity objects?
   – Is there a evolutionary connection between narrow and broad-line objects?
6. Is the nature of the starburst-AGN connection dependent on look-back time?

Some of these questions should be testable in the near future. For instance,
in the merger-induced scenario starburst ages should increase along the sequence
“starburst → cool ULIRGs → warm ULIRGs → quasars”. Detailed spectroscopic
studies should be able to answer this question. Increasingly sensitive techniques
and instruments to detect obscured AGNs (e.g., infrared and X-ray spectroscopy
from the ground and with satellites) will allow to put better constraints on the
contribution of the AGN to the total energy output of galaxies (questions #2).
Questions regarding the starburst-AGN connection in the early universe will
obviously be more difficult to answer. For these we probably have to wait for
the next generation of ground-based telescopes and astronomical satellites to
decipher the nature of the starburst-AGN connection in proto-galaxies. In the
meantime, much effort should be invested in predicting what we should expect
to see!

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