# LOW-LUMINOSITY ACTIVE GALACTIC NUCLEI

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ABSTRACT. I review the basic properties of low-luminosity active galactic nuclei (LLAGNs) — objects in which activity similar to, but intrinsically milder than, that in QSOs and luminous Seyferts is believed to be present. Until recently, most LLAGNs were first recognized as such and studied at optical wavelengths, but evidence for activity and valuable information concerning its nature are now also being obtained in many other spectral ranges. Low-ionization nuclear emission-line regions (LINERs) are the most common LLAGNs; in a large fraction of them the emission lines come from clouds of gas probably photoionized by a nonstellar continuum, rather than heated by shocks. It is also clear, however, that there could be substantial heterogeneity among LINERs, particularly those with extended emission; some may be produced by cooling flows, supernova-driven winds, and galaxy interactions or mergers. LLAGNs can easily be hidden from sight in a variety of ways, including obscuration by galactic or circumnuclear disks and dilution by bursts of star formation. Direct imaging, spectroscopy, and spectropolarimetry can be used to isolate the different components, especially with high spatial and/or spectral resolution. A surprising result is that Seyfert nuclei are sometimes found in dwarf and very late-type galaxies. The nearby Sd III-IV galaxy NGC 4395 contains the intrinsically faintest known Seyfert 1 nucleus, with a broad H$\alpha$ luminosity only $\sim$ 0.1 that of M81. The idea that the apparent "activity" in some galaxies is a direct consequence of vigorous star formation has some strong supporting evidence, and should seriously be considered. As an example, I focus on the peculiar supernova 1987F, whose optical spectrum bears a striking resemblance to that of typical Seyfert 1 nuclei.

## 1. Introduction

It is now well established that activity in the nuclei of galaxies occurs over a very wide range of luminosities, and manifests itself in many ways across the electromagnetic spectrum. This review covers low-luminosity (intrinsically weak) active galactic nuclei (LLAGNs), concentrating on LINERs (Heckman 1980), examples of hidden activity, and Warmers (Terlevich and Melnick 1985). In some cases it has not yet been established with certainty that the physical processes are indeed comparable to those found among QSOs and bright Seyfert 1 nuclei. Much work has been done in this field during the past few years, and it is not possible to include all important results; reviews by Keel (1985), Heckman (1987), and others may be consulted for further information. Luminosity functions of LLAGNs, as well as direct evidence for the presence of supermassive black holes in normal galaxies, are omitted, since these topics are described by Khachikian (1989) and Dressler (1989), respectively. A value of $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ is assumed throughout this paper.

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I define AGNs to be those nuclei whose observed characteristics are not *obviously* dominated by stars, their remnants, or thermally ionized clouds of gas. This is unlike the case in starburst nuclei, for instance, whose emission lines, continua, and other properties are very similar to those in classical H II regions. Star formation may, however, be *linked* with the AGN phenomenon; it could lead to the genesis or fueling of the supermassive black hole ("monster") usually thought to be at the heart of every AGN (e.g., Shapiro and Teukolsky 1986; Sanders *et al.* 1988), or it may be a direct consequence of the activity (Boroson and Oke 1982). I also emphasize that stellar and purely thermal processes *might*, in fact, be producing some of the activity itself, especially in low-luminosity systems, but the evidence is recent, subtle, and still controversial; it will be discussed in § 3 and § 5.

## 2. Classical AGNs, LLAGNs

### 2.1. OBSERVED CHARACTERISTICS

Classical AGNs are objects in which the nonstellar activity at some wavelength is luminous, easily visible, and relatively uncontaminated by the surrounding starlight or H II regions. They generally include QSOs and quasars, blazars, Seyfert 1 and luminous Seyfert 2 galaxies, broad-line and narrow-line radio galaxies, certain X-ray galaxies, and N galaxies. Some of their main properties are the presence of (*a*) a very prominent, spatially unresolved or slightly resolved nucleus, (*b*) broad (FWHM $\approx$ 4000 km $s^{-1}$) permitted emission lines of hydrogen and other elements, (*c*) narrower (FWHM $\approx$ 400 km $s^{-1}$) permitted and forbidden emission lines spanning a wide range of ionization (e.g., [O I] to [Fe XIV]), (*d*) a featureless, nonstellar, roughly power-law continuum ($f_\nu \propto \nu^{-\alpha}$) at X-ray, optical, ultraviolet (UV), infrared (IR), and radio wavelengths, (*e*) UV and IR excesses above this continuum, (*f*) rapid variability of the permitted emission lines or the continuum at many wavelengths, (*g*) jets of radio, optical, or X-ray emission, (*h*) extended double radio lobes, (*i*) significant polarization not attributable to interstellar dust, and (*j*) a compact, flat-spectrum radio core. Not all of these need be seen in a given object (e.g., jets have so far been discovered in few Seyfert 1 galaxies), but strong correlations are often found; an example is the proportionality (except in blazars) between the measured intensities of broad H$\beta$ emission and the nonstellar optical continuum (Yee 1980; Shuder 1981). LLAGNs presumably exhibit many or most of the above characteristics, but at much weaker levels.

The nonstellar continua of QSOs typically have absolute blue magnitudes ($M_B$; $\lambda \approx 4500$ Å) between $-30$ and $-23$ (i.e., $L_B \approx 10^{11} - 10^{14}\, L_\odot$), while those of Markarian Seyfert 1 nuclei lie in the range $-23$ to $-18$ ($L_B \approx 10^9 - 10^{11}\, L_\odot$). The well-known continuity in many observed characteristics of these objects gives strong evidence for the idea that their physical properties are also similar. Broad permitted emission lines are either absent or hidden in Seyfert 2 galaxies, but a nonstellar ionizing continuum is usually, though not always (e.g., Adams and Weedman 1975; Terlevich and Melnick 1985), believed to produce the narrow lines. In this paper a LLAGN is loosely defined to be an AGN whose *nonstellar* continuum has $M_B \gtrsim -18$ mag. If we assume $M_B \approx -2.5 \log L(\text{H}\alpha) + 84.7$ (where $\log x \equiv \log_{10} x$), as empirically derived by Weedman (1985) for the nuclei of Markarian galaxies having *broad* H$\alpha$ emission with luminosity $L(\text{H}\alpha)$, we find that $M_B \gtrsim -18$ corresponds to $L(\text{H}\alpha) \lesssim 10^{41}$ ergs $s^{-1}$. For simplicity, the same limiting $L(\text{H}\alpha)$ is used for narrow-line AGNs. The nucleus of the nearby, frequently studied spiral galaxy NGC 4051 was for many years the least luminous known Seyfert 1 ($M_B \approx -16$; Véron 1979).

A galaxy with an even fainter active nucleus is M81 ($d \approx 3.3$ Mpc); weak, broad H$\alpha$ emission was discovered by Peimbert and Torres-Peimbert (1981) and confirmed by Shuder and Osterbrock (1981). An accurate measurement of the broad H$\alpha$ luminosity, $L(\text{H}\alpha)$

$\approx 1.2 \times 10^{39}$ ergs $s^{-1}$ (Filippenko and Sargent 1988; hereafter FS88), together with the relation given above, yields $M_B \approx -13.0$ for the nonstellar continuum, which has not yet been detected. The nucleus of this galaxy is also a strong, variable X-ray source (Elvis and Van Speybroeck 1982; Barr *et al.* 1985), as well as a bright, compact, variable, flat-spectrum radio source (e.g., Crane, Giuffrida, and Carlson 1976; Kellermann *et al.* 1976). There is almost no doubt that its activity is similar to that in QSOs; it could reasonably be called a "microquasar" (Elvis 1984). The standard interpretation for LLAGNs such as M81 (e.g., Filippenko 1988) is that they have rather small central black holes ($M \lesssim 10^6 \, M_\odot$), or are accreting material at very sub-Eddington rates.

How faint can active galaxies be, and how abundant are they? These are interesting questions for many reasons. Since all QSOs are assumed to occur in galaxies, most density evolution models of AGNs would be severely affected by the discovery of low-level activity in a majority of local galaxies, and pure density evolution would be entirely ruled out (e.g., Weedman 1985). LLAGNs are also valuable because they are present nearby, and can be studied in detail, providing information about the host galaxies and the emission-line regions. They give us the opportunity to explore the physical mechanisms of AGNs to extreme limits, such as very small accretion rates. Moreover, they might help improve our understanding of the cosmic X-ray background.

We certainly *expect* there to be at least a few LLAGNs in the local universe, simply because QSOs existed in the past and faded with time as their fuel supply was steadily depleted. The recent discovery (Yee and De Robertis 1989) of broad H$\alpha$ emission in some low-redshift 3CR radio galaxies situated in moderately rich environments, together with the tendency for radio-loud quasars to be found in clusters of galaxies when beyond a redshift of $\sim 0.5$ (Yee and Green 1987), provides some support for this idea. Continuity between QSOs and Seyfert 1 nuclei further suggests the existence of LLAGNs, but there *might* be a lower limit to the activity. If so, it could be of fundamental importance, like the lower mass limit ($\sim 0.08 \, M_\odot$) of main-sequence stars. Before drawing any general conclusions, however, it is imperative that we ascertain whether LLAGNs of a given type are genuine cousins of classical AGNs, having a compact "monster" in their nuclei, or whether their properties can be attributed to other physical phenomena.

## 2.2. THE SEARCH FOR LLAGNs

How do we find LLAGNs? Clearly, we need to look at relatively nearby objects. Surveys for bright point-like nuclei are not terribly useful from the ground because starlight is so dominant, but they should be fruitful with the Hubble Space Telescope (*HST*), especially at UV wavelengths where the ratio of stellar to nonstellar continua is smaller than at optical wavelengths. Ground-based searches for optical variability or for a featureless optical continuum are plagued by the same problems. With few exceptions, observations with *IUE* have been of insufficient quality for the detection of broad Ly$\alpha$, Mg II $\lambda$2800, or C IV $\lambda$1549 emission in previously unknown LLAGNs; *HST* will partly remedy this. Although previous X-ray surveys did not yield many new LLAGNs, future missions with greater sensitivity (e.g., *AXAF*) should be very productive. At IR wavelengths, unfortunately, one is easily confused by thermal emission from dust, especially due to poor spectral and spatial resolution. Of course, optical observations of *IRAS* "warm galaxies" showed that many were previously unrecognized Seyferts (e.g., de Grijp *et al.* 1985), but most of these are intrinsically quite luminous and heavily reddened. Observations at radio wavelengths are also useful (Condon and Dressel 1978; van der Hulst, Crane, and Keel 1981), except that once again emission from the disk of the galaxy can dominate that of the nucleus. Recent surveys with the VLA, however, have led to the identification of many LLAGNs (e.g., Wrobel 1989). Similar studies having high spatial resolution and excellent sensitivity can be expected to yield far more LLAGNs in the near future.

As shown by Keel (1983), Filippenko and Sargent (1985; hereafter FS85), and others, optical spectroscopy of galactic nuclei is a very good method for finding LLAGNs, especially if the observations are made near the Hα region and care is taken to remove the underlying starlight. Moreover, a large amount of information concerning physical conditions can be obtained from the emission lines, since they are excellent diagnostics of density, temperature, and ionization mechanism, and the relevant physics is fairly well understood. Also, optical observations are reasonably easy to make, given the great number of available telescopes with high-quality spectrographs and sensitive detectors such as charge-coupled devices (CCDs). For these reasons, and because of my personal research interests, optical results will be stressed in this review. It is important to remember, however, that despite the dominance of optical spectroscopy in defining samples of LLAGNs, observations at *many* wavelengths are needed to quantify their overall properties, and to determine whether the activity is truly a low-level version of that in QSOs. Extremely luminous far-IR galaxies may, for example, be highly obscured AGNs, but the radio interferometric studies of Norris (1989) suggest that many of them are powered by violent starbursts.

One particularly fruitful technique for discovering LLAGNs is to search for broad Hα emission in optical spectra of nearby galactic nuclei. Together with W. Sargent, I am doing this in a systematic manner for a sample of the 500 optically brightest galaxies in the northern sky (see FS85 for initial results). NGC 4639, illustrated by Filippenko and Sargent (1986; hereafter FS86), is an excellent example of a bright, nearby Shapley-Ames galaxy whose Seyfert 1 characteristics had previously not been noticed. The prominent, broad Hα emission line has FWHM $\lesssim 4000$ km $s^{-1}$ and full width near zero intensity (FWZI) $\sim 8000 - 9000$ km $s^{-1}$, but the corresponding component of Hβ is very weak, possibly due to reddening. Indeed, the spectrum at blue and visual wavelengths is comparable to those of normal, inactive galaxies devoid of strong emission lines. A majority of old redshift surveys of galaxies did not include the red spectral region, so it is possible that quite a few LLAGNs of this type have been overlooked. This is especially the case because in most LLAGNs the broad Hα emission line is very weak, requiring careful deconvolution of the Hα + [N II] λλ6548, 6583 blend for detection and measurement (Stauffer 1982; Keel 1983).

The emission lines in classical AGNs are almost certainly the result of photoionization of gas by the UV and X-ray nonstellar continua (see Ferland and Shields [1985] for a comprehensive review). The intensities of the *narrow* emission lines generally satisfy, very roughly, [O III] λ5007/Hβ $\approx 10$ and [N II] λ6583/Hα $\approx 1$, and high-ionization lines such as [Ne V] λ3426 and He II λ4686 are present (e.g., Osterbrock 1977; Koski 1978). [O I] λ6300 is considerably stronger than in H II regions, whose O and B stars produce Strömgren spheres with thin, well-defined boundaries between the zones of neutral and ionized hydrogen. Thus, one can find LLAGNs by conducting a spectroscopic survey of galaxies, looking for weak emission lines whose relative intensities are similar to those above.

A very significant study of this kind that revealed many LLAGNs is that of Phillips, Charles, and Baldwin (1983). Objects having [O III] λ5007 $\gg$ Hβ in their nuclei were chosen from spectral descriptions of galaxies published by Sandage (1978). These were found to resemble classical Seyferts, having similar relative line intensities and profiles, but with substantially lower luminosities and smaller line widths. Continuity with classical AGNs was also demonstrated at radio and X-ray wavelengths. This suggested that Seyfert nuclei occur in at least 5% of all bright galaxies, rather than in only 1%–2% as previously believed. It was also pointed out that active galaxies with even lower emission-line luminosities might be common, having been missed by objective-prism and UV-excess surveys.

Note that although Shuder and Osterbrock (1981) claimed that any galaxy having [O III] λ5007/Hβ $> 3$ and FWHM $> 300$ km $s^{-1}$ is active, H II regions can easily satisfy the first requirement if they are metal-poor and contain very early-type stars. Moreover, it is now known that many AGNs are inconsistent with the second criterion, as first stressed by Phillips, Charles, and Baldwin (1983). In fact, the widths of forbidden lines in Seyfert nuclei and LLAGNs often seem to be comparable to those of stellar absorption lines in their nuclear regions (Whittle 1989; Wilson and Heckman 1985). Of course, some outstanding exceptions exist (e.g., NGC 1068, NGC 1275, Mrk 3), and they undoubtedly contributed to the belief that the "narrow" forbidden lines must be relatively broad in Seyfert galaxies. Aside from the usual distinction between Seyfert 1 and 2 galaxies (Khachikian and Weedman 1971), breadth of the forbidden lines is considered to be of secondary importance, compared with line intensity ratios, in modern classification schemes of AGNs.

## 3. Low Ionization Nuclear Emission-Line Regions (LINERs)

### 3.1. PHOTOIONIZATION VERSUS SHOCK HEATING

It has long been known that the intensity ratios of emission lines in the nuclei of some galaxies do not resemble those in H II regions, planetary nebulae, or Seyfert galaxies. Specifically, the [N II] $\lambda6583/\mathrm{H}\alpha$ intensity ratio can be $\gtrsim 3$ in some cases (Burbidge and Burbidge 1962). Heckman (1980) showed that these "low-ionization nuclear emission line regions" (LINERs) are very common ($\sim 1/3$ of all galaxies); he defined them as having [O II] $\lambda3727$/[O III] $\lambda5007 \gtrsim 1$ and [O I] $\lambda6300$/[O III] $\lambda5007 \gtrsim 1/3$. Later surveys by Stauffer (1982), Keel (1983), FS85, Véron-Cetty and Véron (1986), and Phillips *et al.* (1986) confirmed and extended this result, showing that 50%–80% of early-type spiral ($\lesssim$ Sb) and elliptical galaxies are LINERs. If the emission lines in LINERs are produced by a relatively flat, nonstellar photoionizing continuum, a reasonable conclusion is that they are low-level examples of the phenomena found in classical AGNs; hence, *most* galaxies could be "active." One must, however, demonstrate that these observational properties are indeed due to QSO-like activity, since other, unrelated, mechanisms may produce similar features.

The close resemblance of the line ratios in NGC 1052, the prototypical LINER, to those of supernova remnants (SNRs) led Fosbury *et al.* (1978) to suggest that heating of gas by shocks is responsible for its emission lines. The same conclusion had earlier been drawn by Koski and Osterbrock (1976), who measured the temperature-sensitive ratio [O III] $\lambda4363$/[O III] $\lambda5007$ in NGC 1052 and derived $T_e \approx 33{,}000$ K, inconsistent with *photoionized* gas in the $\mathrm{O}^{++}$ zone ($T_e \lesssim 20{,}000$ K). The nuclei of other galaxies, such as M87 (Ford and Butcher 1979), PKS 1718–649 (Fosbury *et al.* 1977), and Heckman's (1980) LINERs, were found to have line intensity ratios similar to those in NGC 1052. They were well explained by shock models (e.g., Dopita 1977; Shull and McKee 1979), and a featureless blue continuum seemed to be absent in most or all cases, so the galaxies were classified as being shock heated. The majority of LINERs are quite well separated from AGNs on the diagnostic diagrams published by Baldwin, Phillips, and Terlevich (1981, hereafter BPT; see Veilleux and Osterbrock 1987 for a refined version). If all of them were indeed heated by shocks, LINERs *might* be physically similar to classical AGNs, but evidence for such a connection would be weak.

There was, however, the possibility that photoionization by a dilute, yet relatively hard, continuum could produce LINER intensity ratios. This was proposed by Kent and Sargent (1979) for the filaments in NGC 1275. Several years later two groups (Ferland and Netzer 1983; Halpern and Steiner 1983) independently compared observations with the results of their photoionization models, which incorporated a low ionization parameter ($U$), and found generally good agreement. The small ratio of ionizing photons to nucleons at the inner face of a gas cloud naturally led to a spectrum dominated by emission lines of neutral and singly ionized atoms, especially if X-rays produced vast regions in which the H ionization fraction was $\sim 0.1$. In fact, a general *continuity* on the BPT diagrams was observed between classical AGNs ($\log U \approx -2$) and LINERs ($\log U \approx -3$ to $-4$).

Despite this apparent continuity, there remained several important problems. The predicted He II λ4686/H$\beta$ ratio, $\sim 0.1 - 0.2$, was larger than observed, but excellent data were sparse at the time. Moreover, Péquignot (1984) demonstrated that the problem could be resolved if LINERs had many ionizing photons between 1 and 4 Ryd, with a cutoff beyond 4 Ryd, as in the thermal emission from a blackbody of temperature $\sim 80,000$ K. This might be taken as evidence for the presence of a hot accretion disk in LINERs, but first we need direct observational confirmation of the excess emission.

Potentially more troublesome was the high value of $T_e$ implied by the [O III] line ratios. Stellar absorption lines surrounding 4363 Å, however, made [O III] λ4363 look too strong (Keel and Miller 1983; Rose and Tripicco 1984; Filippenko 1985), so the actual value of $T_e$ was lower than previously quoted. Moreover, detailed analyses of line profiles (Filippenko and Halpern 1984; Carswell *et al.* 1984; FS88), as well as theoretical models of integrated line intensity ratios (Péquignot 1984; Stasińska 1984; Binette 1985), showed unambiguously that there is a *range* of densities in the narrow-line regions (NLRs) of LINERs. Although densities derived by using the simple assumptions of Filippenko and Halpern (1984) can be somewhat too large (Whittle 1985), it appears that [O III] is produced by intermediate-density gas ($n_e \approx 10^6 - 10^7$ cm$^{-3}$), and $T_e \lesssim 20,000$ K is found in the O$^{++}$ zone. This value is consistent with photoionization models and *incompatible* with shocks.

Quite direct evidence for the hypothesis that LINERs are low-luminosity QSOs is the detection of broad H$\alpha$ emission (FWZI $\gtrsim 4000$ km s$^{-1}$) in some galaxies of this type (Stauffer 1982; Keel 1983). FS85 found or suspected broad H$\alpha$ in $\sim$ 40% of Heckman's (1980) original list of LINERs, including NGC 1052. The central powerhouse in a majority of these may be intrinsically weak because of a small black hole and/or slow accretion relative to the Eddington rate. Some, however, may have evolved from luminous QSOs, and therefore contain supermassive black holes accreting at extremely sub-Eddington rates.

Observations at radio wavelengths also provide strong support for a physical continuity between classical AGNs and LLAGNs. Heckman (1980) pointed out that LINERs often have compact, flat-spectrum radio cores in their nuclei, reminiscent of those in Seyfert 1 galaxies (see also O'Connell and Dressel 1978); presumably the radiation is nonthermal. Sadler (1987) found that at least 80% of optically bright, nearby elliptical galaxies have a central radio source with $\log(P/\text{W-Hz}^{-1}) \gtrsim 19.5$. Many of those observed at several frequencies have flat-spectrum cores, and continuity of the observed properties was used to argue that Es and S0s are often low-luminosity counterparts of typical radio galaxies. These results were extended by the work reported by Wrobel (1989). In many cases it is possible to determine whether current star formation or a LLAGN dominates the radio emission by examining both the 6 cm radio power and the far-IR luminosity (Wunderlich, Klein, and Wielebinski 1987). VLBI observations of normal galaxies have sometimes revealed compact (few pc) cores much weaker than, but similar in appearance to, those in quasars (Jones, Sramek, and Terzian 1981).

There are numerous additional arguments for a connection between many LINERs and classical AGNs. A seminal paper by Rose and Searle (1982) showed that the radial gradients of emission lines in the Seyfert 2/LINER "transition" galaxy M51 are consistent with photoionization of gas by nonstellar radiation from the nucleus. Detailed studies of faint lines in other transition galaxies (Osterbrock and Dahari 1983), as well as statistical investigations of strong lines (Keel 1983), suggest that most LINERs can best be explained by photoionization. Moreover, a nonthermal 10 $\mu$m excess may be present in NGC 1052 (Rieke, Lebofsky, and Kemp 1982), and the intensity of [S III] λλ9069, 9532 relative to other lines can best be explained by photoionization (Diaz, Pagel, and Terlevich 1985). Halpern and Steiner (1983) showed that many LINERs and transition galaxies are weak X-ray sources, resembling obscured Seyfert 1 nuclei; NGC 2110, in particular, has an X-ray spectrum quite similar to those of type 1 Seyferts and quasars (Mushotzky 1982).

Apparently "normal" galaxies, which might actually harbor weak LINER characteristics, are sometimes relatively strong X-ray emitters (Fabbiano 1986; Maccacaro *et al.* 1987). Also, featureless optical continua are found in some LINERs (e.g., Filippenko 1985), and it is reasonable to expect that these extend to UV wavelengths, especially since *IUE* measurements of UV emission lines in a few bright LINERs show better consistency with photoionization models than with shocks (Goodrich and Keel 1986).

Obviously, the actual *presence* of an ionizing continuum in LINERs is of crucial importance to photoionization models. Is there any evidence for it? Goodrich and Keel (1986) detected a UV continuum, possibly of nonstellar origin, in NGC 4579, but only starlight in NGC 5005. Bruzual, Peimbert, and Torres-Peimbert (1982) found an upper limit to the nonstellar UV continuum in M81 which is marginally consistent with the emission-line fluxes, although not very convincing. The UV continua of NGC 4258, NGC 4594, and M51 are adequate to explain the observed emission-line fluxes (Ellis, Gondhalekar, and Efstathiou 1982), but the presence of stellar absorption lines indicates that the ionizing photons probably come from hot young stars. No evidence for a photoionizing continuum has been found in NGC 1052 (Fosbury *et al.* 1981). The origin of the spatially unresolved, fairly flat continuum found in NGC 3998 (Reichert, Wu, and Filippenko 1988) is not yet certain, despite the detection of broad Mg II $\lambda$2800 and H$\alpha$ emission lines. Reddening may be a problem in most of these LINERs; nevertheless, it appears that the hypothesis of nonstellar photoionization is currently not well supported by the UV observations. *HST* will be of great importance in seeing whether this is a general result.

## 3.2. LINERs: A HETEROGENEOUS CLASS?

The absence of an obvious photoionizing continuum in the few LINERs observed thus far at UV wavelengths emphasizes the possibility that many LINERs might, in fact, be shock heated after all. It is wise to look more closely at the evidence before we conclude beyond reasonable doubt that every LINER, the most common type of LLAGN, is related to the QSO phenomenon. Although photoionization models work very well for LINERs as a whole, in *most* objects only the strong lines have been measured (e.g., Keel 1983), and these are reproduced equally well, or almost as well, with shock models. In his excellent review talk at IAU Symposium 121, Heckman (1987) discussed evidence for the mini-QSO interpretation of LINERs, but also showed that there are very good reasons to believe that many LINERs have a number of other possible origins. It is worthwhile to summarize his arguments here, and to provide additional ones.

The first serious alternative is that some LINERs may be cooling accretion flows (Hu, Cowie, and Wang 1985), since optical spectra of LINERs closely resemble those of extended gas in some giant elliptical galaxies such as M87 (Ford and Butcher 1979). X-ray emitting gas cools and flows quasi-hydrostatically into the bottom of the potential well in the center of a galaxy (perhaps in a cluster), emitting LINER-like optical and UV line radiation when its temperature drops below a few hundred thousand degrees. Shocks driven into the cooling filaments also affect the line emission, as does X-ray heating of the dense clouds by the surrounding hot gas. Fabian *et al.* (1986), in fact, have suggested that small cooling flows can explain the presence of LINERs in ordinary galaxies. This is supported by the discovery by Phillips *et al.* (1986) that LINERs are often found in those E and S0 galaxies showing detectable X-ray emission. Moreover, long-slit spectra of some early-type galaxies demonstrate that the emission-line intensity ratios are not very dependent on projected radial distance from the galactic nucleus. A good example is NGC 6500, spatially resolved spectra of which are illustrated by Filippenko (1984). This is very difficult to understand in the context of photoionization models, since $U \propto (nr^2)^{-1}$ and the density appears to be independent of radial distance ($r$) from the nucleus. It may, however, be consistent with the cooling flow hypothesis.

Another idea is that some LINERs, particularly those with spatially *extended* emission (as above), may be starburst-driven winds. A high rate of star formation in the nuclear regions of galaxies could lead, through the copious production of supernovae, to a rapid wind (several 1000 km $s^{-1}$) of hot gas expanding outward along the disk's minor axis (Chevalier and Clegg 1985). Ambient clouds are shock heated by this wind, and produce an optical LINER-like spectrum as well as X-ray emission. McCarthy, Heckman, and van Breugel (1987) show that this is likely to be the case along the minor axis of M82, where the emission-line gas has a LINER spectrum. NGC 253 exhibits similar evidence. Luminous *IRAS* galaxies such as Arp 220 and NGC 6240 (Rieke *et al.* 1985) also frequently show LINER-like nebulae consisting of bubbles, filaments, arcs, and other extended features. Another excellent example is NGC 3079, which shows a tremendous bipolar outflow definitely associated with shocks or cooling gas (Filippenko and Sargent 1989*a*). In some cases the observed ionization may be due to a combination of an AGN and starbursts.

Yet one more possibility for the origin of some LINERs is galaxy collisions and interactions. Widespread shocks should occur when galaxies merge, collide, or simply experience a close gravitational encounter. This would especially be the case if the two galaxies were gas rich, as proposed for NGC 6240 by Fosbury and Wall (1979) and for Cen A by Phillips (1981). If even a small amount of gas were captured from an interacting galaxy, cloud-cloud collisions could produce a LINER spectrum at the weak level seen in many E galaxies and early-type spirals. Finally, LINERs may indeed be due to photoionization, but the source of the photons might be extremely hot stars (Terlevich and Melnick 1985) rather than an active nucleus in which a monster is lurking; see § 5.

The evidence presented above suggests that LINERs may form a rather heterogeneous class, with a number of possible physical mechanisms producing the observed emission. Even in a given galaxy there could be several relevant processes. Measurement of [O III] $\lambda4363$ in the off-nuclear gas, where densities are likely to be far lower and spatially less variable than in the nuclei, should eventually tell us whether collisional excitation in thermally ionized gas plays an important role in some LINERs. It is important to clearly recognize at this time that simply seeing a LINER spectrum does *not* guarantee that the galaxy contains an active nucleus similar to that seen in QSOs and luminous Seyferts. This is especially true when the LINER emission is *extended* throughout a substantial area of the galaxy, or when there is no evidence for broad permitted emission lines in the nucleus. Of course, even in objects whose emission lines are concentrated near the nucleus, *some* shock emission may be present despite the possible dominance of photoionization; after all, we *see* velocities of a few 100 km $s^{-1}$ (narrow-line profiles), and cloud collisions would give rise to the observed line ratios. Composite models of this type have been explored by Aldrovandi and Contini (1984), but much more work remains to be done in this area.

## 4. Hidden AGNs and LLAGNs

In recent years, it has become clear that AGNs are often able to camouflage some aspects of their activity, such as the broad permitted emission lines. Indeed, they hide themselves in galaxies that appear much less active, or even quite normal. LLAGNs can be especially difficult to find because their luminosities are low compared with those of entire galaxies or the circumnuclear regions of galaxies. In this section I discuss some of the most important special cases of this kind, as well as a few general classes of hidden LLAGNs.

### 4.1. OBSCURED SEYFERT 1 NUCLEI

The nuclei of certain galaxies identified in X-ray surveys were found to exhibit narrow, high-excitation emission lines very similar to those of Seyfert 2 nuclei, which are typically much weaker X-ray emitters. Upon closer examination (e.g., Véron *et al.* 1980; Shuder 1980), it was discovered that essentially all these "narrow-line X-ray galaxies" reveal a weak, low contrast, broad component of $H\alpha$ emission, and in some cases broad $H\beta$ as well. The spectra resemble those of Seyfert 1.8 or 1.9 galaxies (Osterbrock 1981). Since the broad-line Balmer decrement is sometimes considerably greater than that of Case B recombination, reddening may be important. The disks of such galaxies are often, but not always, highly inclined to the plane of the sky (Lawrence and Elvis 1982); hence, their Seyfert 1 nuclei would be brighter if viewed face-on. Continuity arguments suggest that a significant number of intrinsically even weaker Seyfert 1 nuclei exist, but have thus far escaped detection because their broad-line regions (BLRs) are blocked along our line of sight.

Undeniable evidence for obscured Seyfert 1 nuclei is provided by observations (Antonucci and Miller 1985) of the famous Seyfert 2 nucleus in NGC 1068: the *polarized* flux has a spectrum indistinguishable from that of a type 1 Seyfert. Since the electric polarization vector is perpendicular to the radio axis, a thick disk or torus must block our direct view of the central source, and hot electrons outside the cauldron scatter radiation into our line of sight. Antonucci (1983) found that the polarization vector is generally perpendicular to the radio axis in Seyfert 2 galaxies, whereas it is parallel in type 1 Seyferts, so the phenomenon observed in NGC 1068 may be quite general. Indeed, Miller (1989) reports that spectropolarimetry of several other Seyfert 2 galaxies yields similar results.

It is significant that Wilson, Ward, and Haniff (1988), among others, have found that extrapolation of the observed nonstellar continua of many Seyfert 2 galaxies cannot account for the great emission-line flux in their NLRs. One likely explanation, of course, is that clouds in the NLRs generally have a much more direct vie of the compact nucleus than we do. Pogge's (1988*a*) discovery of a high-ionization emission-line "cone" in NGC 1068 supports this hypothesis, as does Miller's (1989) observations of broad Balmer lines scattered from an off-nuclear H II region in the same object. NGC 4388, an edge-on Seyfert 2 galaxy, also exhibits cones of highly ionized gas (Pogge 1988*b*). These are roughly cospatial with the radio emission seen along its minor axis (Stone, Wilson, and Ward 1988).

NGC 4388 is of additional interest because FS85 detected weak, broad $H\alpha$ emission in its apparent nucleus, while Shields and Filippenko (1988, 1989) showed that this component is *spatially extended* up to $10''$, especially in regions occupied by Pogge's (1988*b*) cones. Whittle *et al.* (1988; see also Whittle 1989) demonstrate that rather broad lines (FWZI $\approx 2000$ km $s^{-1}$) can sometimes be attributed to bulk motions of gas along the radio axes of Seyfert galaxies, but this is unlikely to be the case in NGC 4388; the centroid of the extended broad $H\alpha$ emission, though uncertain due to contamination from adjacent [N II] lines, does not appear significantly offset from the systemic velocity of the galaxy. Moreover, its FWZI is comparable and very large ($\sim 4000$ km $s^{-1}$) at all measured locations. Reflection off the numerous clouds of gas and dust in NGC 4388 is the most probable explanation for the extended broad $H\alpha$, and it should be tested with spectropolarimetry. Note that Hutchings and Craven (1988) have detected off-nuclear broad $H\beta$ emission along an optical jet in Mrk 110, and interpret it in terms of the bulk flow model. For reasons similar to those discussed above, I believe that scattering is actually the dominant process, although hot electrons rather than dust could provide the necessary medium. To my knowledge, Mrk 110 and NGC 4388 are the only galaxies known to have extended *broad-line* emission. A polarized blue continuum in a high-excitation cloud of gas at a projected distance $\sim 8$ kpc from the nucleus of PKS 2152–69 (Tadhunter *et al.* 1987; di Serego Alighieri *et al.* 1988), however, is probably also produced by scattering of beamed radiation.

## 4.2. COMPOSITE NUCLEI

Active nuclei are often hidden by regions of star formation, especially in late-type galaxies. Radio emission from SNRs and H II regions can easily mask the nonthermal continuum from a LLAGN. Similarly, IR wavelengths are plagued by thermal radiation from dust, and optical emission lines are the main coolants of H II regions. Even the presence of X-rays is not a definitive sign of nuclear activity; binary X-ray sources, SNRs, and hot gas from supernova-driven winds can conspire to fool the observer (Fabbiano 1986). At most wavelengths, the difficulties of detecting a LLAGN are compounded by the relatively poor spatial or spectral resolution. Optical imaging in conditions of good atmospheric seeing ($\sim 1''$), however, can be used to distinguish between circumnuclear H II regions and LLAGNs, especially when done in conjunction with spatially-resolved spectroscopy. This is demonstrated particularly well by Edmunds and Pagel (1982) for the barred "hot-spot" galaxy NGC 1365, which has a Seyfert 1 nucleus.

Although it is preferable to use long-slit spectra, even optical spectra obtained through a single aperture can often reveal H II regions directly superposed on the nuclei of active galaxies. Véron *et al.* (1981) illustrate this for two objects; the emission-line profiles are probably composites of narrow lines having relative strengths typical of H II regions, and broader lines with intensity ratios similar to those in LINERs or in the NLRs of Seyfert galaxies. This is shown more clearly in IC 5135 (Shields and Filippenko 1989). In some objects the *integrated* emission-line intensity ratios give conflicting results when placed on the diagnostic diagrams of BPT. For example, a nucleus having substantial [Ne V] $\lambda$3426 or He II $\lambda$4686 emission, which should be extremely weak in gas photoionized by OB stars, may show an [O III] $\lambda 5007/\mathrm{H}\beta$ intensity ratio more typical of H II regions. With moderately high spectral resolution ($\sim 1$ Å), it is much easier to distinguish between, and therefore quantify, the contributions of the H II regions and the LLAGN to the overall emission-line spectra. Moreover, relatively broad Balmer absorption lines from the young stellar populations in H II regions can be removed from the data, providing better measurements of the superposed Balmer emission lines.

Currently available spectrographs permit the detection of extremely weak LLAGNs in galactic nuclei dominated by H II regions. A good example is NGC 4303, in which FS86 noticed [N II] $\lambda$6583 emission having a considerably broader base (FWZI $\approx 800$ km s$^{-1}$) than H$\alpha$. The presence of weak LINER or Seyfert 2 emission in NGC 4303 was recently confirmed by Kennicutt, Keel, and Blaha (1989) from observations of the [O III] $\lambda$5007 and H$\beta$ profiles. They find that similar characteristics seem to be present in a remarkably large fraction ($\sim 50\%$) of late-type galaxies, if observed with sufficiently high spectral and spatial resolutions. If the H II regions were absent, the mild activity in these nuclei would be much easier to detect. It will be interesting to see how the emission-line fluxes compare with those of LINERs in early-type galaxies. Such studies of line profiles should certainly be continued with *HST*. Moreover, a nonstellar continuum might be detectable at UV wavelengths in some cases. Other spectral regions should also be useful, preferably in conjunction with one another (e.g., Keel 1984). Careful observations at radio and far-IR wavelengths, for example, might eventually allow us to distinguish between stellar and nonstellar activity in relatively late-type (Sbc) galaxies.

## 4.3. DWARF AND VERY LATE-TYPE GALAXIES

It has often been pointed out that a majority of known AGNs and LLAGNs (LINERs, etc.) occur in luminous, rather early-type galaxies, with few of them being found in Hubble types Sbc or later (e.g., Heckman 1980; Keel 1983). The favored interpretation has been that the formation of black holes and/or the retention of gas are inhibited in the fairly shallow potential wells of late-type and dwarf galaxies. The studies of very weak LINERs and Seyfert 2s discussed in the preceeding section, however, indicate that *mild* activity may nevertheless be present in many late-type galaxies. Moreover, some genuine Seyfert 1 and 2 nuclei do exist in Sc galaxies. Is there any evidence for the presence of Seyferts in Sd, irregular, or dwarf galaxies?

The answer is yes, but few such objects are currently known. An excellent example of a dwarf galaxy with Seyfert characteristics is G1200 – 2038 (Kunth, Sargent, and Bothun 1987). The galaxy itself is well approximated by an exponential disk of scale length ~ 1.4 kpc, diameter 9 kpc ($V = 25.0$ mag arcsec$^{-2}$ level), and absolute visual magnitude −17.6. A spectrum of the nucleus reveals emission lines spanning a wide range of ionization, from [O I] to [Ne V], but the general ionization level is somewhat lower than that of a typical Seyfert 2 galaxy (Koski 1978). The nucleus of G1200 – 2038 is spatially unresolved and has $M_V \approx -17.7$, so it can be considered a LLAGN. Unlike other LLAGNs, however, the high ratio (~ 1.1) of nonstellar to stellar luminosity is more representative of QSOs. The intrinsic widths of the emission lines (FWHM ≈ 320 km s$^{-1}$) are much greater than would be expected in a dwarf galaxy. There also seems to be a broader (FWHM ≈ 900 km s$^{-1}$), blueshifted base to the Balmer lines, although weaker wings of this type in the strong [O III] lines imply that the emission does not originate in a high-density BLR.

NGC 4395 (Sd III-IV, $d \approx 2.6$ Mpc, $M_B \approx -16.4$ mag) is another galaxy which will help define the extreme range of conditions capable of supporting AGNs. Recent observations (Filippenko and Sargent 1989*b*) have shown that the star-like nucleus emits a narrow-line spectrum similar to that in G1200 – 2038, with emission lines of very high ionization (up to [Ne V] and [Fe X]). Photoionization by a reasonably hard continuum is almost certainly responsible for their relative strengths, but [O I] λ6300 and [S II] λλ6716, 6731 are unusually intense with respect to [N II] λλ6548, 6583, as illustrated in Figure 1. Unlike G1200 – 2038, very broad components are clearly visible in the permitted-line profiles, but not in the forbidden lines. The FWZI of Hα is ~ 7000 km s$^{-1}$, and that of the weaker He II λ4686 emission appears to be as high as ~ 10,000 km s$^{-1}$. The luminosity of the broad Hα line is ~ $1.1 \times 10^{38}$ ergs s$^{-1}$, about 0.1 that in M81. Hence, NGC 4395 has the intrinsically weakest known Seyfert 1 nucleus; $M_B \approx -10.4$ mag is derived from Weedman's (1985) relation (see §2.1). This is roughly the absolute magnitude of the most luminous single supergiant stars! If NGC 4395 were much farther away, so that the spectroscopic entrance aperture included a large amount of extranuclear light, its spectrum would have been dominated by emission lines from H II regions and continuum from OB associations, making the Seyfert activity difficult to detect.

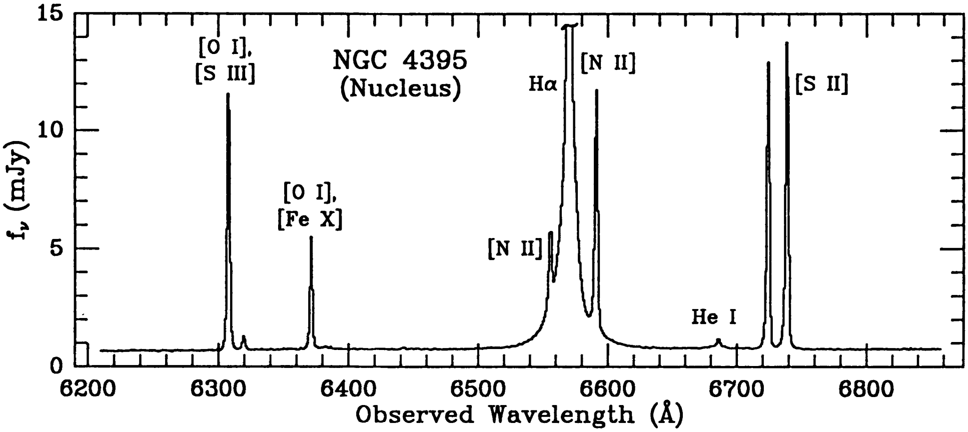

*Figure 1:* CCD spectrum of the central 2″×4″ of NGC 4395, obtained with the 5 m reflector at Palomar Observatory on 7 April 1988 UT. The heliocentric radial velocity is ~ 320 km s$^{-1}$. The luminosity of the broad Hα is the lowest measured in any Seyfert 1 nucleus.

It is very important to obtain additional observations, at all wavelengths, of LLAGNs in dwarf or very late-type galaxies such as those described here. They offer counterexamples to the conventional wisdom that activity is restricted to early-type galaxies with large bulges. If a massive black hole is ultimately responsible for the observed phenomena in the nucleus of NGC 4395, we must explain how it was able to form in this particular object, but not in a majority of other extended, low-mass galaxies. On the other hand, perhaps most dwarf and very late-type galaxies can, in principle, be active, but are usually quiescent because the fueling mechanism does not operate efficiently. Basically, we do not yet know what conditions are necessary for a galaxy to have an active nucleus.

## 5. Warmers: A Different Point of View

### 5.1. THE HYPOTHESIS

In spite of the strong evidence for heterogeneity among LINERs (§3.2), it is easy to get the impression from the above discussion that the nuclei of many or most galaxies are at least mildly active, being the tail end of a distribution that includes QSOs and luminous Seyfert 1 nuclei. This conclusion is particularly natural to draw if we restrict ourselves to those galaxies in which the activity (radio, X-rays, LINER-like intensity ratios, etc.) is concentrated in the nucleus and its immediate vicinity. If so, this is a fundamental constraint; it affects our understanding of luminosity functions, duty cycles for activity, physical mechanisms, and many other aspects of AGNs.

Before jumping on the bandwagon, however, we should pause and carefully consider the evidence. Are we carrying our arguments too far? Specifically, can some LLAGNs be explained by processes that do not require the existence of supermassive black holes and other nonstellar exotica? After all, in a *majority* of galaxies all we must really explain are the intensity ratios of a few strong, narrow emission lines. Could the observed activity be *directly* linked to bursts of star formation and stellar remnants?

In one form or another, this hypothesis has already been considered, and largely dismissed, several times in the case of luminous Seyfert 1 nuclei and quasars; there seem to be too many reasonable arguments against it (Lawrence 1987, and references therein). The possibility that stars produce the activity seen in LINERs, however, has only recently been investigated in detail. In a seminal paper, Terlevich and Melnick (1985) showed that ionizing radiation from evolved, very massive ($M \gtrsim 60\ M_\odot$) stars in metal-rich H II regions can produce emission-line intensity ratios typical of Seyfert 2 nuclei and LINERs. These Wolf-Rayet stars, which they call "Warmers" (extreme WC or WO stars), have effective surface temperatures of $(1-2) \times 10^5$ K; plenty of high-energy ionizing photons are therefore emitted. A key point is that stellar mass loss increases with increasing metal abundance in massive stars, so that very massive stars formed in high-metallicity environments can end their lives as bare He-C-O cores with surface temperatures comparable to those of the hottest known nuclei of planetary nebulae, but with considerably higher luminosities.

Calculations show that after 3 million years, the ionizing continuum of a cluster created during a large burst of star formation (initial mass function slope = 3.0; Lequeux 1979) is nearly a power law, $f_\nu \propto \nu^{-1.5}$, with a cutoff at ~ 20 Ryd. Thus, the resulting emission-line spectrum from surrounding clouds of gas having roughly solar composition closely resembles that of Seyfert 2 galaxies, and fits even better than the results of pure power-law photoionization models, which require rather low abundances (~ 0.3 solar). Moreover, the weak featureless continuum observed in some type 2 Seyferts may be the reddened spectrum of the ionizing cluster. As the cluster ages, the emission-line spectrum evolves into that of a LINER with a blue continuum, because of the relative dearth of very high-energy photons despite the presence of many reasonably hot stars. A smaller starburst, with few extremely massive stars, gives rise to a lower ionization parameter; hence, there would be an absence of high-ionization emission lines in the observed spectrum, and a general deficit of blue photons, making it appear like a LINER with a red continuum. Most LINERs in early-type galaxies are of this type, but the peculiar spectrum of NGC 404 (FS86) is very similar to that expected in a blue LINER; hence, NGC 404 may have previously been a Seyfert 2 galaxy. The apparent absence of Wolf-Rayet emission features near 4640 – 4650 Å in the spectra of LINERs is not a serious problem because the continuum from normal stars is usually so bright, and has not yet been subtracted thoroughly enough.

Terlevich, Melnick, and Moles (1987; hereafter TMM) extended their starburst model, and attempted to answer many significant questions. They concluded, among other things, that the widths of forbidden lines in LINERs and Seyfert 2 galaxies, as well as the distribution of LLAGNs among different Hubble types, is consistent with the starburst model. In fact, motivated by the success of their earlier work, as well as by a consideration of luminosities, the nature of the underlying continuum, and other factors, TMM postulated that typical *Seyfert 1 nuclei* may also ultimately be produced by starburst activity.

TMM distinguished between two different possibilities for massive stars: high mass-loss rate (high metallicity), and low mass-loss rate (low metallicity). When the mass-loss rate is high, massive stars evolving away from the main sequence lose their outer layers by stellar winds, reverse their tracks on the Hertzsprung-Russell diagram, and eventually become very hot WO stars, ending their lives (Begelman and Sarazin 1986; Schaeffer, Cassé, and Cahen 1987) as Type Ib supernovae (SNe Ib) devoid of hydrogen. If the mass-loss rate is low, on the other hand, the entire envelope cannot be removed by stellar winds. Hence, the stars spend their He-burning time as red supergiants, eventually becoming SNe II (hydrogen present). High-velocity gas (SN ejecta) will therefore exist in the nuclear regions, and may account for the broad emission lines seen in type 1 Seyfert nuclei.

As further discussed by Terlevich and Melnick (1988*a*), when the ionizing flux is dominated by SN activity, there should be much variability, especially in objects with expected SN rates of $\sim 1\ \mathrm{yr}^{-1}$. They discuss two different time scales of variability: (*a*) flares of $\sim 10^{49-50}$ ergs, lasting a few weeks, directly from SNe II, and (*b*) longer-term ($t \approx 1500$ days) variations of total energy $\sim 10^{52}$ ergs, from evolution of the SN remnants. A density of $n \approx 10^6\ \mathrm{cm}^{-3}$ is assumed for the interstellar medium; these are high-density environments in the *nuclear* regions of galaxies. Comparison with published time scales of variability in the BLR yields remarkably consistent results, and is used as supporting evidence for the starburst origin of AGNs. Terlevich and Melnick (1988*b*) even show that a recent variation in the Seyfert galaxy NGC 5548, interpreted by Peterson and Ferland (1986) as an accretion event, may actually have been the explosion of a possible Wolf-Rayet star similar to that which gave rise to SN 1983K (Niemela, Ruíz, and Phillips 1985).

## 5.2. AN OBSERVATIONAL LINK BETWEEN SNe AND SEYFERTS?

Despite the interesting possibilities raised by the starburst/Warmers hypothesis, there are a number of difficulties that need to be investigated. Indeed, the proposal has generally been viewed with considerable skepticism by the astronomical community, at least as an explanation for *most* AGNs and LLAGNs (e.g., FS86); the list of problems is quite long. Where, for example, are all of the "progenitor starbursts" of LLAGNs in the nuclei of early-type galaxies? How are vigorous bursts of star formation supposed to form at these locations, when there seems to be a general dearth of gas? Moreover, what inhibits the formation of easily recognizable LINERs in the nuclei of late-type starburst galaxies?

I believe that the idea of Warmers has great potential as an explanation for *some* (not all!) LINERs and type 2 Seyferts, since most of the objections to the proposal have reasonable solutions or cannot be applied to certain individual objects. Until recently, however, I was skeptical that the model could be extended to *any* type 1 Seyferts, partly because their spectral characteristics differ so greatly from those of SNe (Oke and Searle 1974), which play an important role in the starburst model of Seyfert 1 nuclei. This skepticism has diminished to some extent during the past year, for reasons described below.

The March 1987 discovery of the peculiar Type II SN 1987F may play a crucial role in future studies of the starburst/Warmers hypothesis (Filippenko 1989). This object was superposed on, or located in, a luminous H II region along one of the spiral arms of the SBc galaxy NGC 4615. Figure 2 shows its optical spectrum, obtained ~ 11 months after discovery. Permitted emission lines of H I and Fe II having widths of several thousand km $s^{-1}$ are superposed on a relatively featureless continuum. The broad features look remarkably similar to those in spectra of radio-quiet type 1 Seyfert nuclei and QSOs (e.g., Osterbrock 1977)! The presence of O I $\lambda$8446 and the Ca II IR triplet further extends the comparison with AGNs (Persson 1988). Only the narrow emission lines, which come from a fairly *low*-excitation H II region around SN 1987F, spoil the correlation. Although the spectrum of SN 1987F changed as the object aged, at all observed times it was similar, in many ways, to spectra of Seyfert 1 nuclei. Moreover, when SN 1987F was discovered it had $M_B \approx -19$ mag, comparable to that of classical AGNs. The progenitor was almost certainly a massive star; the ejecta consist of $\gtrsim 3\ M_\odot$. SN 1988I, another peculiar SN II, also resembled a type 1 Seyfert (Filippenko 1989), but the data are not as extensive.

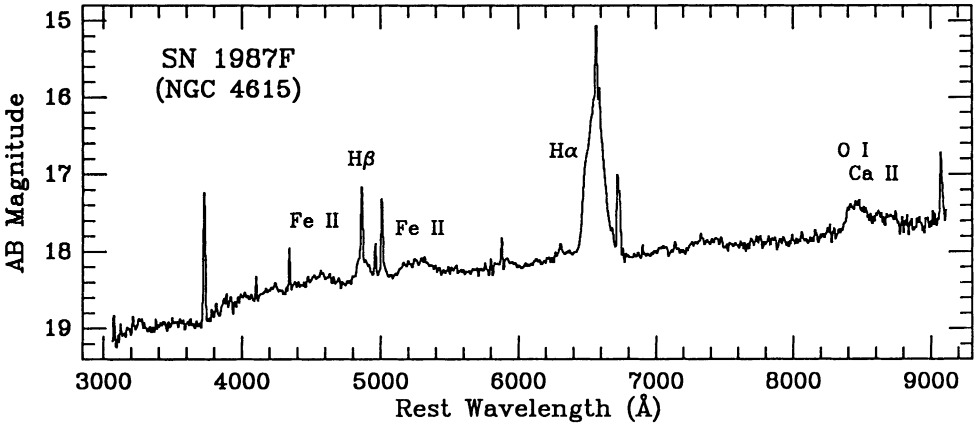

*Figure 2:* CCD spectrum of SN 1987F in NGC 4615, obtained with the 3 m reflector at Lick Observatory on 24 February 1988 UT, roughly 11 months after discovery. AB magnitude $= -2.5 \log f_\nu - 48.6$, where the units of $f_\nu$ are ergs $s^{-1}$ $cm^{-2}$ $Hz^{-1}$. Broad permitted emission lines are marked. Narrow lines arise from the surrounding H II regions.

To be sure, detailed comparisons reveal several fairly subtle spectroscopic differences between SN 1987F and typical type 1 Seyferts at optical wavelengths (Filippenko 1989). On the other hand, had SN 1987F occurred in the nucleus of a normal galaxy, a low-resolution spectrum undoubtedly would have led to a Seyfert 1 classification for the galaxy, especially if some Warmers were present to produce high-ionization narrow lines. If we further *assume* that physical conditions (e.g., a dense interstellar medium, as may have been the case for SN 1987F) in certain galactic nuclei somehow enhance the production of SNe like SN 1987F, then the spectrum could remain Seyfert-like for long periods of time, and exhibit variability as well. Thus, it is possible that a few galaxies have been misclassified as type 1 Seyferts, especially if only one or two low-dispersion spectra of them were taken.

There are, of course, many difficulties with this scenario as a *general* explanation for Seyfert 1 galaxies. The UV excess observed in many AGNs cannot be produced by SNe, and is unlikely to be emission from Warmers; nor is the hard X-ray spectrum easy to explain. Rapid X-ray variability of AGNs is another outstanding puzzle, as is the apparent *absence* of broad H$\alpha$ variability in the low-luminosity type 1 Seyfert M81 (FS88). Certain details of the SN 1987F spectrum, such as the fact that Na I D, rather than He I, seems to account for the weak emission near 5900 Å, are also troublesome. Furthermore, unless the initial mass function is highly skewed towards massive progenitors of SNe such as SN 1987F, the required rate of star formation may be prohibitively large. Numerous other potential problems can easily be conceived.

It is nevertheless possible that *some* catalogued type 1 Seyfert galaxies, especially those of low luminosity, owe their observed characteristics to objects such as SN 1987F; we simply do not know enough about the evolution of SNe and their remnants in dusty, dense environments. M82 provides a case in point: many transient radio emitters, almost *certainly* SNe, have been discovered in this galaxy by Kronberg, Biermann, and Schwab (1985), but their characteristics are peculiar, causing Bartel *et al.* (1987) to reject SNe for their origin. The ideas promoted by Terlevich and collaborators should be pursued in greater detail, lest we miss important new insights into the physical nature of AGNs.

## 6. Concluding Remarks

It is my hope that this review of LLAGNs has illustrated the diversity of mild activity in galactic nuclei, as well as the degree to which our knowledge of the intrinsic physical processes is limited. If we search hard enough, we find that most, or possibly all, luminous galaxies are active or have the potential to be active. It may even be that dwarf galaxies and late-type spirals harbor massive black holes in their nuclei, although it is not clear how these are formed. There is, of course, a natural urge to explain observed phenomena with the fewest assumptions and theories; the apparent continuity between LLAGNs and classical AGNs is comforting from this point of view, at least to me. On the other hand, there is strong evidence for heterogeneity among LINERs, the most common LLAGNs; we must therefore not be blind to the possibility that the apparent activity is produced by many different physical mechanisms, perhaps unrelated to the "monsters" generally invoked to explain quasars. Unraveling the mysteries of LLAGNs will continue to occupy our time for many years, and I'm sure we all look forward to using modern new telescopes, detectors, and theoretical approaches in our quest for the answers.

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