Published in "The Physics of LINERs in View of Recent Observations", ed. M. Eracleous, A. P. Koratkar, C. Leitherer, & L. C. Ho (San Francisco: ASP), 1996, p.103.

OPTICAL SPECTROSCOPY OF LINERS AND LOW-LUMINOSITY SEYFERT NUCLEI

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ABSTRACT. An unprecedentedly large number of LINERs has been discovered in a recently completed optical spectroscopic survey of nearby galaxies, allowing several statistical properties of the host galaxies and of the line-emitting regions to be examined reliably for the first time. As a consequence of the many detections and some revised classifications, the detailed demographics of emission-line nuclei have been updated from those given in older surveys. Consistent with previous studies, it is found that LINERs are extremely common in the present epoch, comprising approximately 1/3 of all galaxies with $B_T \lesssim 12.5$ mag. If all LINERs are nonstellar in origin, then they are the dominant constituents of the active galactic nucleus population. Many fundamental characteristics of LINERs closely resemble those of low-luminosity Seyfert nuclei, although several aspects of their narrow-line regions appear to differ in a systematic manner. These differences could hold important clues to the key parameters controlling the ionization level in active nuclei. Lastly, a substantial fraction of LINERs has been found to contain a broad-line region, yielding direct evidence, at least in these objects, of a physical link between LINERs and classical Seyfert 1 nuclei and QSOs.

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1. INTRODUCTION

This workshop has repeatedly stressed the utility of observations in previously underused spectral regions, particularly the ultraviolet and X-rays, for understanding the physical nature of low-ionization nuclear emission-line regions (LINERs; Heckman 1980b). Nevertheless, the amount of data on LINERs available from space-based instruments is still very small, limited by a combination of the long exposure times necessary to detect the faint signal in these sources and the usual oversubscription of spacecraft time. Thus, statistical studies of LINERs, which require large quantities of data to be gathered in ``survey" mode, still must rely on more traditional ground-based capabilities. This contribution reviews the current status of optical spectroscopic observations of LINERs. Using a recently completed survey of nearby galaxies, I will summarize the demographics of LINERs in the context of other emission-line nuclei. Next, a number of statistical properties of LINERs will be compared with those of low-luminosity Seyfert nuclei, with the hope that such a comparison may shed some light on the parameters of the host galaxy nuclei that influence the various manifestations of nuclear activity. Many of the properties of these faint nuclei are being scrutinized for the first time, and some interesting trends, not obvious or otherwise overlooked in older surveys, will be noted. Finally, I address the fraction of LINERs that show evidence of broad-line emission akin to that seen in Seyfert 1 nuclei and QSOs; this subset of LINERs provides strong support for the hypothesis that a large fraction of all LINERs truly share the same physical origin as other classes of active galactic nuclei (AGNs).

Excellent reviews covering some aspects of the topics presented here, but based on older work, have been given by Keel (1985), Heckman (1987), and Filippenko (1989, 1993). It should be emphasized at the outset that the material presented here refers exclusively to *compact* LINERs ($r \lesssim$ 200 pc) found in the central region of galaxies, and not to LINER-like nebulosities sometimes observed in other environments (see Filippenko in these proceedings for an overview of these systems).

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2. DEFINITIONS AND CLASSIFICATION OF EMISSION-LINE NUCLEI

It is important to remind ourselves of the definition of LINERs. Although rigorous boundaries have little physical meaning and are, to some extent, arbitrary, classification is operationally necessary. Heckman (1980b) originally defined LINERs strictly using the optical forbidden lines of oxygen: [O II] λ 3727 > [O III] λ 5007 and [O I] λ 6300 > 0.33 [O III] λ 5007. Compared with the spectra of Seyfert nuclei or H II regions, the low-ionization states of oxygen in the spectra of LINERs are unusually strong relative to its high-ionization states. Recognizing the arbitrariness of this definition, Heckman drew attention to a group of ``transition objects" whose spectra were intermediate between those of ``pure" LINERs (as defined above) and classical Seyfert nuclei.

As a consequence of the near coincidence between the ionization potentials of hydrogen and neutral oxygen, the collisionally-excited [O I] line in an ionization-bounded nebula arises predominantly from the ``partially-ionized zone," wherein both neutral oxygen and free electrons coexist. In addition to O^0, the conditions of the partially-ionized zone are also favorable for S^+ and N^+, whose ionization potentials are 23.3 eV and 29.6 eV, respectively. Hence, in the absence of abundance anomalies, [N II] λλ 6548, 6583 and [S II] λλ 6716, 6731 are strong (relative to, say, Hα) whenever [O I] λλ 6300, 6363 are strong, and vice versa. This theoretical expectation and the empirical evidence that extragalactic H II regions rarely exhibit [N II] λ 6583 / Hα $\gtrsim$ 0.6 (e.g., Searle 1971) have led some subsequent investigators to short-cut Heckman's original definition of LINERs. For instance, it has become customary to classify emission-line objects solely on the basis of the [N II] / Hα ratio (e.g., Keel 1983b; Keel et al. 1985; Phillips et al. 1986; Véron-Cetty & Véron 1986). While this convention does permit a convenient first-order separation between nuclei photoionized by stars (small [N II] / Hα) and those photoionized by a harder, AGN-like spectrum (large [N II] / Hα), it provides no information on the excitation level of the AGN-like objects - in other words, one cannot distinguish LINERs from Seyfert nuclei. There are two additional complications. A classification scheme that relies on [N II] / Hα alone obviously is sensitive to variations in the abundance of N, which appears to be enhanced in some galactic nuclei (Storchi-Bergmann & Pastoriza 1989, 1990; Ho, Filippenko, & Sargent 1996d). The net effect would be to falsely designate star-forming nuclei having enhanced N abundance as AGNs. Moreover, the reliability of the [N II] / Hα ratio depends critically on the accuracy of the separation between the emission and absorption components of the Hα line. Although the ability to model and remove the stellar contribution to the integrated spectra is an inherent limitation to any method of classification (see Section 3 and Section 4), it is preferable to use as many line ratios as possible to strengthen confidence in the classification assignment.

In the work to be discussed below, I will be using the classification criteria advocated by Veilleux & Osterbrock (1987), which are motivated in part by the principles of Baldwin, Phillips, & Terlevich

(1981). Based on the dereddened line-intensity ratios [O III] λ 5007 / Hβ, [O I] λ 6300 / Hα, [N II] λ 6583 / Hα, and [S II] $\lambda\lambda$ 6716, 6731 / Hα (Hβ and Hα refer only to the narrow component of the line), the Veilleux-Osterbrock system is not only relatively insensitive to extinction corrections, but also conveniently falls within the spectral range of the optical survey to be described in Section 4. For concreteness, the following definitions will be adopted: H II nuclei ([O I] < 0.08 Hα, [N II] < 0.6 Hα, [S II] < 0.4 Hα), Seyferts ([O I] $\geq$ 0.08 Hα, [N II] $\geq$ 0.6 Hα, [S II] $\geq$ 0.4 Hα, [O III] / Hβ $\geq$ 3), and LINERs ([O I] $\geq$ 0.17 Hα, [N II] $\geq$ 0.6 Hα, [S II] $\geq$ 0.4 Hα, [O III] / Hβ < 3). Although the adopted definition of LINERs differs from that of Heckman, inspection of the full optical spectra of Ho, Filippenko, & Sargent (1993) reveals that emission-line nuclei classified as LINERs based on the Veilleux & Osterbrock diagrams almost invariably also satisfy Heckman's criteria. This is a consequence of the inverse correlation between [O III] / Hβ and [O II] / [O III] in photoionized gas with fairly low excitation ([O III] / Hβ $\lesssim$ 3; see Fig. 2 in Baldwin et al. 1981).

In addition to these three categories of nuclei, Ho et al. (1993) identified a class of ``transition objects" (in retrospect, a poor choice of terminology) whose [O I] strengths are intermediate between those of H II nuclei and LINERs. Although O-star models with an appropriate choice of parameters can account for their line-intensity ratios of these objects (Filippenko & Terlevich 1992), an alternative explanation is that these objects are composite systems having both an H II region and a LINER component (Ho et al. 1993). We will define transition objects using the same criteria as for LINERs, except that 0.08 Hα $\lesssim$ [O I] < 0.17 Hα.

It should be emphasized that the classification process is not always straightforward, since the three conditions involving the low-ionization lines do not hold simultaneously in all cases. In view of potential selective N enhancement in galactic nuclei, less weight is given to the [N II] / Hα ratio than to either [O I] / Hα or [S II] / Hα. [O I] / Hα, if reliably determined, deserves the most weight, since it is most sensitive to the shape of the ionizing spectrum. Figure 1 shows sample spectra of the various classes of objects outlined above.

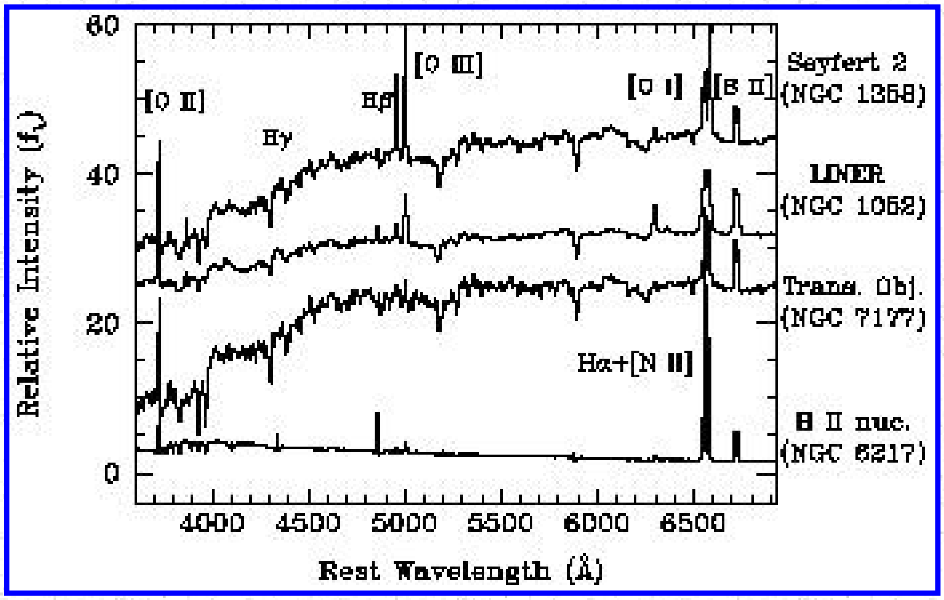

Figure 1. Sample optical spectra of the various classes of emission-line nuclei.

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3. PREVIOUS SURVEYS

It was apparent from some of the earliest redshift surveys that the central regions of galaxies often show evidence of strong emission lines (e.g., Humason, Mayall, & Sandage 1956). A number of studies also indicated that in many instances the spectra revealed abnormal line-intensity ratios, most notably the unusually great strength of [N II] relative to Hα (Burbidge & Burbidge 1962, 1965; Rubin & Ford 1971). That the optical emission-line spectra of some nuclei show patterns of low ionization was recognized from time to time, primarily by Osterbrock and his colleagues (e.g., Osterbrock & Dufour 1973; Osterbrock & Miller 1975; Koski & Osterbrock 1976; Costero & Osterbrock 1977; Grandi & Osterbrock 1978; Phillips 1979), but also by others (e.g., Disney & Cromwell 1971; Fosbury et al. 1977, 1978; Danziger, Fosbury, & Penston 1977; Penston & Fosbury 1978; Stauffer & Spinrad 1979).

Most of the activity in this field culminated in the 1980s, beginning with the recognition (Heckman, Balick, & Crane 1980; Heckman 1980b) of LINERs as a major constituent of the extragalactic population, and followed by further systematic studies of larger samples of galaxies (Stauffer 1982a, b; Keel 1983a, b; Filippenko & Sargent 1985; Phillips et al. 1986; Véron & Véron-Cetty 1986; Véron-Cetty & Véron 1986; see summary in Table 1). At optical wavelengths the nuclear component in a ``normal" galaxy is generally much weaker than the stellar background of its bulge. In addition to having very small equivalent widths, many of the emission lines are severely blended and diluted by stellar absorption lines. Thus, adequate removal of the stellar contribution to the integrated spectrum is an absolute prerequisite to any quantitative analysis of the emission-line component for the sources in question. In this regard, with the exception of the survey by Filippenko & Sargent (which will be considered later), the rest suffer from several major drawbacks (Table 1). Although most of the surveys attempted some form of starlight subtraction, the accuracy of the methods used tended to be fairly limited (see discussion in Ho, Filippenko, & Sargent 1996c), the procedure was sometimes inconsistently applied, and in two of the surveys subtraction was largely neglected. The problem is exacerbated by the fact that the effective aperture used for the observations was quite large, thereby admitting an unnecessarily large amount of starlight. Furthermore, most of the data were collected with rather poor spectral resolution ($\delta\lambda \approx$ 10 Å). Besides losing useful kinematic information, severe blending between the emission and absorption components further compromises the ability to separate the two.

Table 1. Optical Spectroscopic Surveys [a] of Nearby Galaxy Nuclei

	No.	δ (deg)	Types	B (mag)	Aper. (")	$\lambda\lambda$ (Å)	$\Delta\lambda$ (Å)	Starlight Subtraction
H	93	$\geq +40$	All	12.0	6	3500–5300 [b]	8	Template
S	139	$\geq -30, \leq +60$	Spirals	13.0	8	4700–7200	10	None [c]
K	93	$\geq -15, \leq +40$	S0/a–Scd	12.0	8	5400–7600	10	Templ.+synthesis
V	320	$< +20$	E–Sc	-- [d]	4	4000–7000 [e]	10 [e]	None or statistical
P	203	≤ -32	E, S0	14.0	2	6100–7100	3	Average template

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[a] H = Heckman et al. 1980; S = Stauffer 1982a; K = Keel 1983a; V = Véron-Cetty & Véron 1986; P = Phillips et al. 1986.

[b] A subset of 22 galaxies was observed in the spectral range 5100–6900 Å with $\Delta\lambda$ = 6 Å.

[c] Template subtraction applied to a small subset.

[d] $M_B \leq -21$ mag and $cz < 3000$ km s^{-1}.

[e] A subset of 149 galaxies was observed around Hα with $\Delta\lambda$ = 4 Å.

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4. THE PALOMAR SURVEY OF NEARBY GALAXIES

Despite the sizable observational effort invested during the last decade, it is clear that much can be gained from a survey having greater sensitivity to the detection of emission lines. The sensitivity can be improved in at least four ways - by taking spectra with higher signal-to-noise ratio (S/N) and spectral resolution, by using a narrower slit to better isolate the nucleus, and by employing more effective methods to handle the starlight correction.

Using a double CCD spectrograph mounted on the Hale 5-m reflector at Palomar Observatory, high quality, moderate-resolution, long-slit spectra were obtained for a magnitude-limited ($B_T \leq$ 12.5 mag) sample of 486 northern ($\delta > 0°$) galaxies (Filippenko & Sargent 1985, 1986; Ho, Filippenko, & Sargent 1995). The red camera covered the range 6210-6860 Å with ~ 2.5 Å resolution, while the corresponding values for the blue camera were 4230-5110 Å and ~ 4 Å. Most of the observations were obtained with a narrow slit (generally 2", and occasionally 1"), and the exposure times were suitably long (up to 1 hr or more for some objects with low central surface brightness) to secure data of high S/N. This survey contains the largest data base of homogeneous and high-quality optical spectra of nearby galaxies yet published. The selection criteria of the survey ensure that the sample is a good representation of the local ($z \approx$ 0) galaxy population (Fig. 2), and the proximity of the objects (median distance = 17 Mpc) enables fairly good spatial resolution to be achieved (typically $\lesssim$ 200 pc).

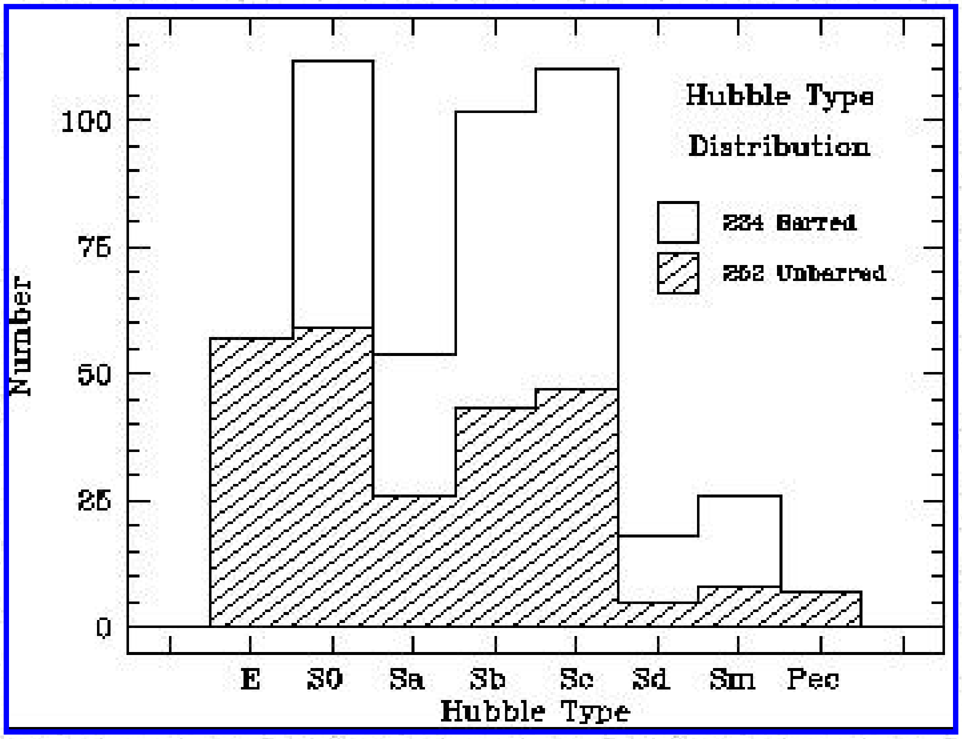

Figure 2. Distribution of Hubble types for the 486 galaxies in the survey. Ordinary (unbarred) galaxies are shown in the hatched histogram, and barred (SB and SAB) galaxies in the unhatched histogram. Classifications taken from de Vaucouleurs et al. (1991).

A common strategy for removing the starlight from an integrated spectrum is that of ``template subtraction," whereby a template spectrum devoid of emission lines is suitably scaled to, and subtracted from, the spectrum of interest to yield a continuum-subtracted, pure emission-line spectrum (e.g., Costero & Osterbrock 1977; Filippenko & Halpern 1984; Filippenko & Sargent 1988; Ho et al. 1993). In practice, the template is derived either from the spectrum of a different galaxy or from the spectrum of an off-nuclear position in the same galaxy. This approach, however, suffers from some limitations. For instance, the absorption-line galaxy chosen as the template may not exactly match the stellar component of the object in question; previous studies generally invested limited observing time to the acquisition of template spectra. In the case where an off-nuclear spectrum is used as the model, it may not be completely free of emission, and one cannot be sure that radial gradients in the stellar population are absent.

To perform the starlight subtraction in a more objective and efficient manner than has been done in the past, a modified version of the template-subtraction technique that takes advantage of the large number of absorption-line galaxies in the survey was developed (Ho et al. 1996c). Given a list of input template spectra and an initial guess of the velocity dispersion, the χ^2-minimization algorithm of Rix & White (1992) solves for the systemic velocity, the line-broadening velocity dispersion, the relative contributions of the various templates, and the general continuum shape. The best-fitting model is then subtracted from the original spectrum, yielding a pure emission-line spectrum. Figure 3 illustrates this process for the H II nucleus in NGC 3596 and for the Seyfert 2 nucleus in NGC 7743. In the case of NGC 3596, the model consisted of the combination of the spectrum of NGC 205, a dE5 galaxy with a substantial population of A stars, and NGC 4339, an E0 having a K-giant spectrum. Note that in the original observed spectrum (top), Hγ, [O III] $\lambda\lambda$ 4959, 5007, and [O I] λ 6300 were hardly visible, whereas after starlight subtraction (bottom) they can be easily measured. The intensities of both Hβ and Hα have been modified substantially, and the ratio of the two [S II] $\lambda\lambda$ 6716, 6731 lines changed. The effective template for NGC 7743 made use of NGC 205, NGC 4339, and NGC 628, an Sc galaxy with a nucleus dominated by A and F stars.

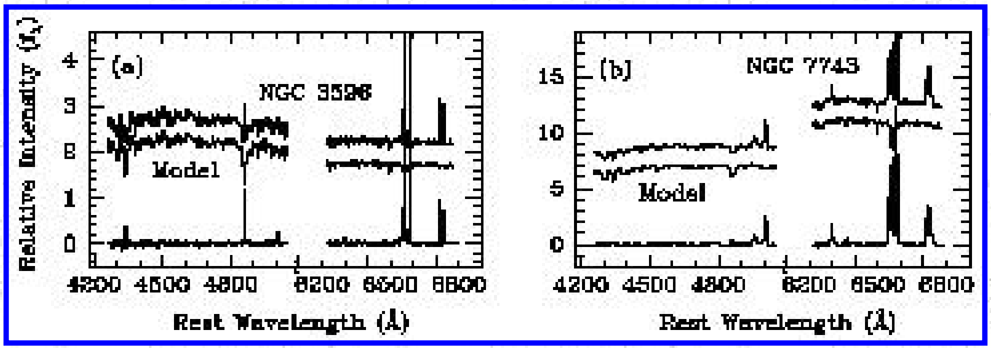

Figure 3. Illustration of the method of starlight subtraction. In each panel, the top plot shows the observed spectrum, the middle plot the best-fitting ``template" used to match the stellar component, and the bottom plot the difference between the object spectrum and the template. In the case of NGC 3596 (*a*), the model was constructed from NGC 205 and NGC 4339, while for NGC 7743 (*b*), the model was derived from a linear combination of NGC 205, NGC 4339, and NGC 628.

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5. DEMOGRAPHICS OF EMISSION-LINE GALAXIES

Although the specific numbers cited differ from one investigator to another, all the older surveys discussed in Section 3 agree that LINERs are extremely common in nearby galaxies. They also concur that the detection rate of LINERs varies strongly with Hubble type, with early-type systems being the preferred hosts; this result essentially confirms what was already found by Burbidge & Burbidge (1962), who noted that most of the galaxies showing enhanced [N II] / Hα ratios tended to be of early type.

Not surprisingly, the Palomar survey likewise finds the same trends. The important distinction, however, is that the results from the present survey are *quantitatively* much more reliable, for reasons already discussed in Section 4, both in a statistical sense as well as on an object-by-object basis. The detection rates of the various classes of emission-line nuclei defined in Section 2 are given in Table 2 and graphically illustrated in Figure 4*a*. The conclusions that can be drawn are the following.

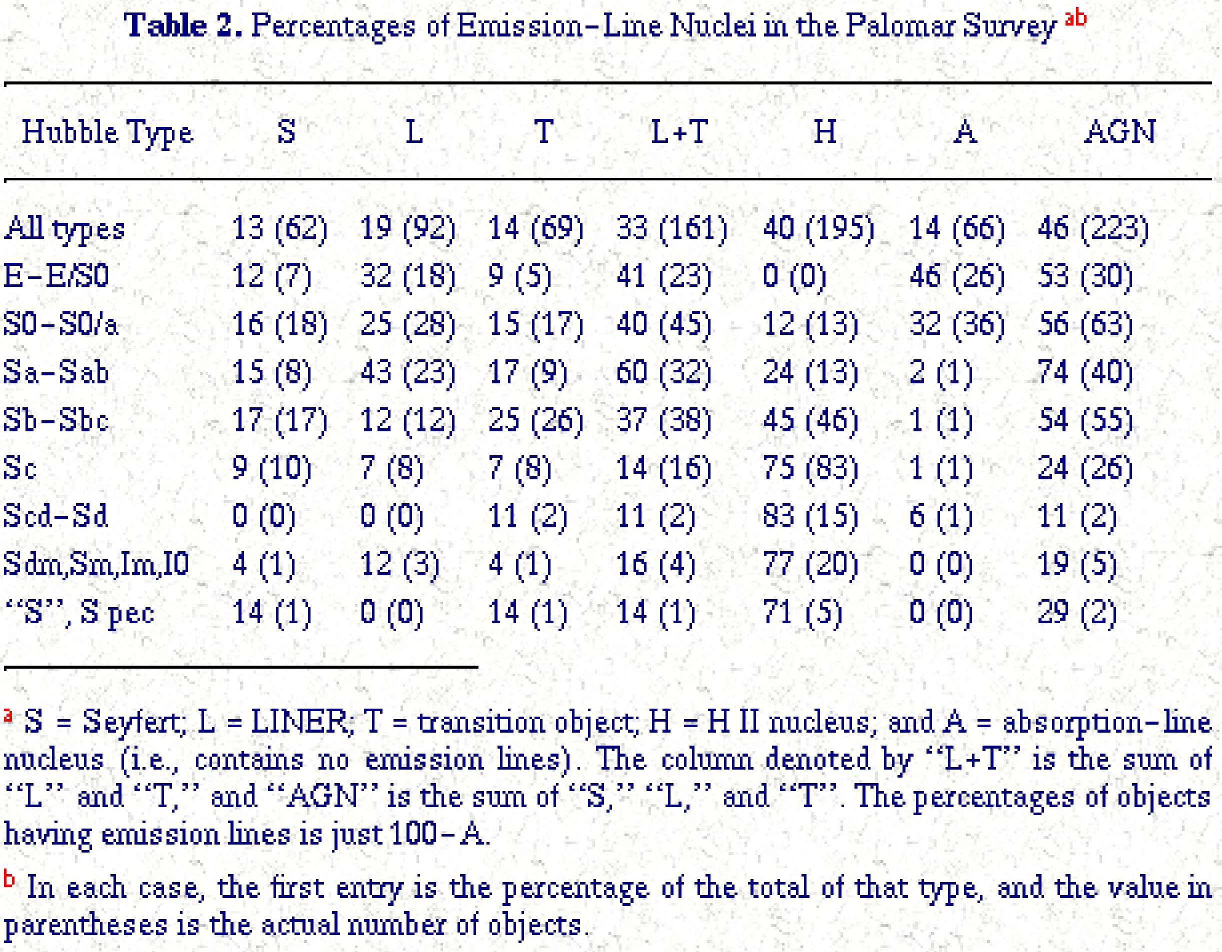

Table 2. Percentages of Emission-Line Nuclei in the Palomar Survey [ab]

Hubble Type	S	L	T	L+T	H	A	AGN
All types	13 (62)	19 (92)	14 (69)	33 (161)	40 (195)	14 (66)	46 (223)
E–E/S0	12 (7)	32 (18)	9 (5)	41 (23)	0 (0)	46 (26)	53 (30)
S0–S0/a	16 (18)	25 (28)	15 (17)	40 (45)	12 (13)	32 (36)	56 (63)
Sa–Sab	15 (8)	43 (23)	17 (9)	60 (32)	24 (13)	2 (1)	74 (40)
Sb–Sbc	17 (17)	12 (12)	25 (26)	37 (38)	45 (46)	1 (1)	54 (55)
Sc	9 (10)	7 (8)	7 (8)	14 (16)	75 (83)	1 (1)	24 (26)
Scd–Sd	0 (0)	0 (0)	11 (2)	11 (2)	83 (15)	6 (1)	11 (2)
Sdm,Sm,Im,I0	4 (1)	12 (3)	4 (1)	16 (4)	77 (20)	0 (0)	19 (5)
“S”, S pec	14 (1)	0 (0)	14 (1)	14 (1)	71 (5)	0 (0)	29 (2)

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[a] S = Seyfert; L = LINER; T = transition object; H = H II nucleus; and A = absorption-line nucleus (i.e., contains no emission lines). The column denoted by “L+T” is the sum of “L” and “T,” and “AGN” is the sum of “S,” “L,” and “T”. The percentages of objects having emission lines is just 100 – A.

[b] In each case, the first entry is the percentage of the total of that type, and the value in parentheses is the actual number of objects.

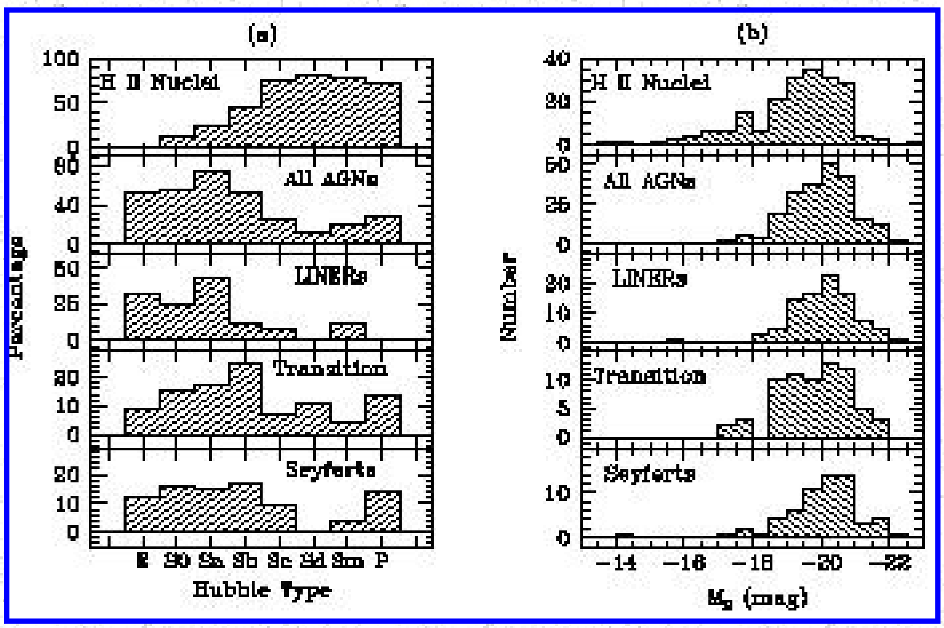

Figure 4. (*a*) Percentage of galaxies with the various classes of emission-line nuclei detected as a function of Hubble type. (*b*) Distribution of the classes of emission-line nuclei as a function of the absolute *B* magnitude of the host galaxy.

1. At the limit of our survey, which is at least 4 times more sensitive to the detection of emission lines than any of the older surveys, most galaxies (86%) exhibit optical line emission in their central few hundred parsecs, implying that ionized gas is almost invariably present. This fraction, of course, represents a lower limit. Keel (1983a) detected emission in all the galaxies he surveyed, but his sample was restricted to spirals; Table 2 confirms that essentially all spirals have nuclear emission lines. The Hubble type distribution of the surveys of Heckman et al. (1980) and Véron-Cetty & Véron (1986) more closely matches that of the present sample, and, in these, the detection rate was only ~ 60%-65%.

2. Seyfert nuclei can be found in at least 10% of all galaxies with $B_T \leq$ 12.5 mag, the vast majority of which (~ 80%) have early Hubble types (E-Sbc). The fraction of galaxies hosting Seyfert nuclei has roughly doubled compared to previous estimates (Stauffer 1982b; Keel 1983b; Phillips, Charles, & Baldwin 1983; Maiolino & Rieke 1995). It is interesting to note that Seyfert nuclei, at least with luminosities as low as those here, do *not* exclusively reside in spirals, as is usually believed (e.g., Adams 1977; Weedman 1977). In fact, galaxies of types E and E/S0 have roughly the same probability of hosting a Seyfert nucleus as those of types between S0 and Sbc.

3. ``Pure" LINERs are present in ~ 20% of all galaxies, whereas transition objects, which by assumption also contain a LINER component, account for another ~ 15%. Thus, if all LINERs can be regarded as genuine AGNs, they truly are the most populous constituents - they make up > 70% of the AGN population (here taken to mean all objects classified as Seyferts, LINERs, and transition objects) and a full 1/3 of all galaxies. The latter statistic broadly supports earlier

findings by Heckman (1980b) and others.

4. The Hubble type distribution of ``pure" LINERs is virtually identical to that of Seyferts; the same can be said for the distribution of absolute magnitudes (Fig. 4*b*), both groups having a median M_B = -20.2 mag. On the other hand, the hosts of many transition objects apparently have somewhat later Hubble types and fainter absolute magnitudes (median M_B = -20.0 mag), consistent with the idea that these systems are composites of ``pure" LINERs and H II nuclei.

5. H II nuclei, in striking contrast to AGNs, occur preferentially in late-type galaxies (Heckman 1980a; Keel 1983a; Terlevich, Melnick, & Moles 1987). Quite surprisingly, not a single elliptical galaxy falls into this category. This is consistent with the survey of early-type (E and S0) galaxies of Phillips et al. (1986); the few objects they identified as having H II nuclei are all classified S0 (two are E-S0). Narrow-band imaging surveys of elliptical galaxies (e.g., Shields 1991) often reveal detectable amounts of warm ($T \approx 10^4$ K) ionized gas in their centers. Although the dominant ionizing agent responsible for the line emission is still controversial (Binette et al. 1994, and references therein), our failure to detect spectra resembling ordinary metal-rich H II regions among the ~ 60 ellipticals in our survey suggests that young massive stars are probably not the culprit, unless the physical conditions in the centers of ellipticals conspire to make H II regions look very different from those seen in the nuclei of S0s and early-type spirals.

Theoretical studies (e.g., Heller & Shlosman 1994) suggest that large-scale stellar bars can be highly effective in delivering gas to the central few hundred parsecs of a spiral galaxy, which may then lead to rapid star formation. Further instabilities may result in additional inflow to smaller physical scales relevant for AGNs. Thus, provided that a reservoir of gas exists, the presence of a bar might be expected to influence the fueling rate, and hence the activity level. Being sufficiently large and unbiased with respect to bar type, the Palomar survey can be used to examine this issue. Ho, Filippenko, & Sargent (1996a, e) find that the presence of a bar does indeed enhance both the probability and rate of the formation of massive stars in galaxy nuclei, but only for spirals with types earlier than Sbc. By contrast, AGNs seem to be altogether unaffected.

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6. Statistical Properties of LINERs and Seyfert Nuclei

6.1. *Emission-Line Luminosity*

In lieu of direct measurement of the nonstellar featureless continuum at optical wavelengths, an almost impossible feat for the low-luminosity sources in question, one might use, as a substitute, an indirect measure such as the luminosity of a narrow emission line powered by the continuum. In luminous AGNs, whose nonstellar optical continuum generally overwhelms the stellar background, the $H\alpha$ luminosity scales linearly with the luminosity of the continuum (Searle & Sargent 1968; Yee 1980; Shuder 1981). However, using line luminosities derived from slit spectroscopy is not without complications, especially for the relatively narrow slit employed in the Palomar survey. For any given object, the amount of line emission sampled will depend on its distance as well as on the physical extent of the line-emitting region. Moreover, circumnuclear H II regions undoubtedly contaminate the line emission at some level (indeed, for transition objects, this is assumed *a priori*). These limitations notwithstanding, it can be argued that a *statistical* examination of such line luminosities might still be of value, as the individual ``fluctuations'' will tend to average out for sufficiently large samples. The $H\alpha$ luminosities for the various classes of emission-line nuclei are shown in Figure 5*a*. The incredible feebleness of the low-luminosity AGNs can be readily appreciated by realizing that a sizable fraction of H II nuclei and disk giant H II regions (e.g., Kennicutt 1988), not to mention starburst nuclei (e.g., Balzano 1983), in fact have much stronger $H\alpha$ luminosities than these sources. Remarkably, the distributions for LINERs and Seyferts appear very similar, both having a median $L(H\alpha) \approx 6 \times 10^{38}$ ergs s^{-1}; transition objects tend to be somewhat less luminous, but the difference is insignificant according to the Kolmogorov-Smirnov (K-S) test. (The probability that the LINERs and transition objects are drawn from the same population, P_{KS}, is 0.16.) The above comparison is not obviously affected by known systematic biases, since all three subclasses have virtually identical distance distributions, modest reddening corrections were consistently applied, and it was already shown (Section 5) that the host galaxies of LINERs and Seyferts are grossly similar.

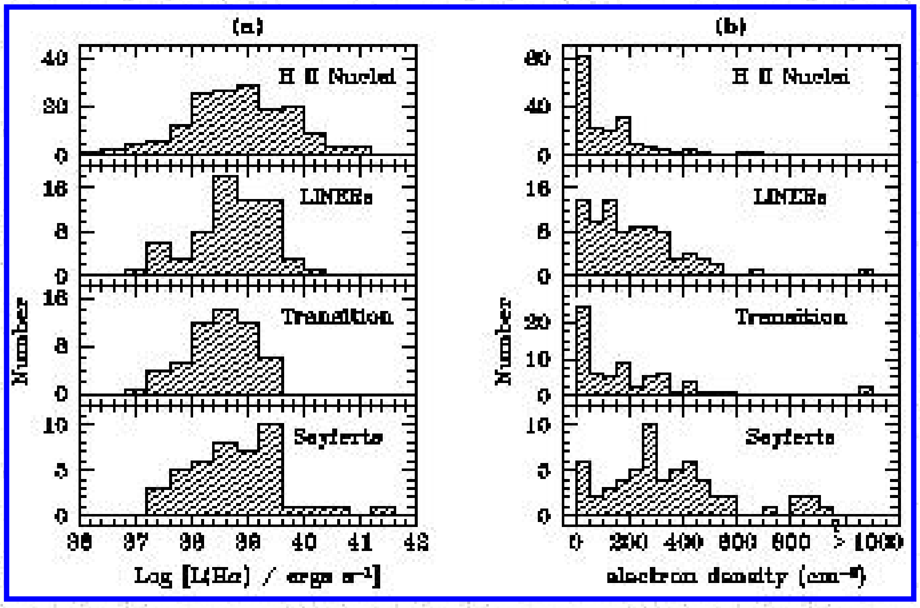

Figure 5. (*a*) Distribution of dereddened luminosities for the narrow Hα emission line. (*b*) Distribution of electron densities derived from [S II] λλ 6716, 6731.

Heckman (1980b) claimed that the line luminosities of LINERs are smaller than those of Seyferts, contrary to what we and Stauffer (1982b) find. The principal reason for this difference appears to be that Heckman used for comparison a sample of Seyferts, taken from Adams & Weedman (1975), which was biased toward luminous sources.

One should be cautious in interpreting these results. Superficially, it appears that both LINERs and Seyferts have the same ``level'' of activity, if one assumes that the narrow-line luminosity is an appropriate yard stick for gauging the power output of the central source. It remains to be demonstrated, however, that the line-continuum relation of luminous AGNs continues to hold for low-luminosity sources. There is preliminary evidence, for instance, that the spectral energy distributions of LINERs and low-luminosity Seyferts may differ appreciably from those of high-luminosity sources (Ho, Filippenko, & Sargent 1996b). If so, the equivalent widths of emission lines, and hence the slope of the line-continuum relation, will vary systematically with luminosity.

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6.2. *Electron Density*

The electron density can be estimated from the ratio of the two [S II] lines, at least for the portion of the narrow-line region (NLR) characterized by densities not greatly in excess of the critical density of [S II] (~ 3 x 10^3 cm^{-3}), above which the lines become collisionally de-excited. As shown in Section 6.4, a range of densities, spanning nearly five orders of magnitude, exists in the NLRs of some LINERs and Seyferts. The [S II] densitometer strictly probes only the low-density regions. Figure 5*b* indicates that LINERs have *smaller* electron densities (median n_e = 175 cm^{-3}) than Seyferts (median n_e = 290 cm^{-3}), and the difference is highly significant according to the K-S test (P_{KS} = 0.00078). Transition objects have smaller densities than LINERs, most notably in a considerable excess of low-density members, as seen in a large fraction of H II nuclei.

These density measurements are in substantial disagreement with previous studies, which typically find densities on the order of 1000 cm^{-3} (Stauffer 1982b; Keel 1983b; Phillips et al. 1986). The discrepancy can be traced to a common culprit, which serves as an excellent lesson in the pitfalls of measuring weak lines in galaxy nuclei. Careful inspection of Figure 3 reveals that [S II] λ6716 is affected by a stellar absorption line due to Ca I λ6718 [see also Fig. 12 of Filippenko & Sargent (1985)]. Since the emission lines in the sources of interest generally have very low equivalent widths (typically 2-3 Å), the absorption feature, though weak, can significantly depress the ratio of [S II] λ6716 to [S II] λ6731; this effect will artificially raise the derived electron density. The older studies in question almost never performed starlight subtraction to the degree of precision required to notice this, thereby systematically overestimating the inferred densities.

It is interesting to point out that the electron densities among Seyfert nuclei appear to decrease with decreasing nuclear luminosity. In a sample of bright, mostly Markarian Seyfert 2 galaxies, Koski (1978) found that the average density, again as determined from [S II], is ~ 2000 cm^{-3}, far greater than that encountered in the present sample of low-luminosity Seyferts. Although the systematic effect discussed above may also affect Koski's measurements to some degree, it probably cannot account for the large difference, especially in view of the much larger emission-line equivalent widths in his sample. The same trend of density variation is also clearly seen in the smaller sample of low-luminosity sources published by Phillips et al. (1983); for the 17 objects in which both [S II] lines were tabulated, I calculate $< n_e > =$ 340 cm^{-3}.

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6.3. *Internal Reddening and Inclination Effects*

Another parameter that can be easily examined is the internal reddening along the line of sight, as inferred from the relative intensities of the narrow Balmer emission lines. The conventional Balmer decrement method, unfortunately, assumes that the extinction arises from a uniform, foreground screen of dust, and it is unclear to what extent such an oversimplified geometry applies to the actual line-emitting regions in galaxy nuclei. The derived reddening values, therefore, should be strictly regarded as lower limits. With this caveat in mind, it is intriguing that LINERs are noticeably *less* reddened than Seyferts (Fig. 6*a*; P_{KS} = 0.0023). That LINERs are also less reddened compared to transition objects is to be expected, since H II nuclei in general are much more heavily extinguished than LINERs [median *E (B - V)* = 0.21 and 0.47 mag for LINERs and H II nuclei, respectively]. These data constitute the first set of reliable reddening measurements for such faint nuclei. In the older surveys, the Balmer decrements were either completely unconstrained (e.g., because only the red part of the spectrum was surveyed) or otherwise very poorly determined because of the difficulties associated with starlight correction. Heckman's (1980b) suspicion that the Hα / Hβ ratios in LINERs may be intrinsically and abnormally high is not supported by the present observations.

How are these results to be interpreted? It is highly instructive to consider the axial ratios, or inclination angles, of the host galaxies for the various subclasses (Fig. 6*b*). Binney & de Vaucouleurs (1981) find that the distribution of apparent axial ratios (*b/a*) of S0s and spirals (Sa-Sd) in the RC2 is essentially flat between 0.2 and 1. The axial ratios for the entire Palomar sample, after excluding ellipticals, Magellanic irregulars (Sdm, Sm, Im), and objects with highly distorted morphologies, are shown in the upper panel of Figure 6*b*. Note that the distribution has a slight positive slope; this property is expected in a magnitude-limited sample, since internal absorption tends to shift edge-on systems above the limiting magnitude (Maiolino & Rieke 1995). The distributions of axial ratios among the various subclasses are quite similar, but some subtle differences can be discerned. Although Seyferts are found in hosts of all inclinations, there appears to be a preference for systems viewed more face-on (larger *b/a*). Such an inclination bias is well known in other samples of Seyfert galaxies (Keel 1980; McLeod & Rieke 1995; Maiolino & Rieke 1995), but it is much less pronounced in the present sample because of our ability to detect weak emission lines. There is also some indication that a similar selection effect is present in LINERs, and, at any rate, Seyferts and LINERs do not have different inclinations. Thus, from geometric considerations alone, these two groups should be equally reddened. The enhanced reddening observed in Seyferts relative to LINERs, therefore, must point to subtle, intrinsic differences present in the physical conditions of their NLRs (Section 9).

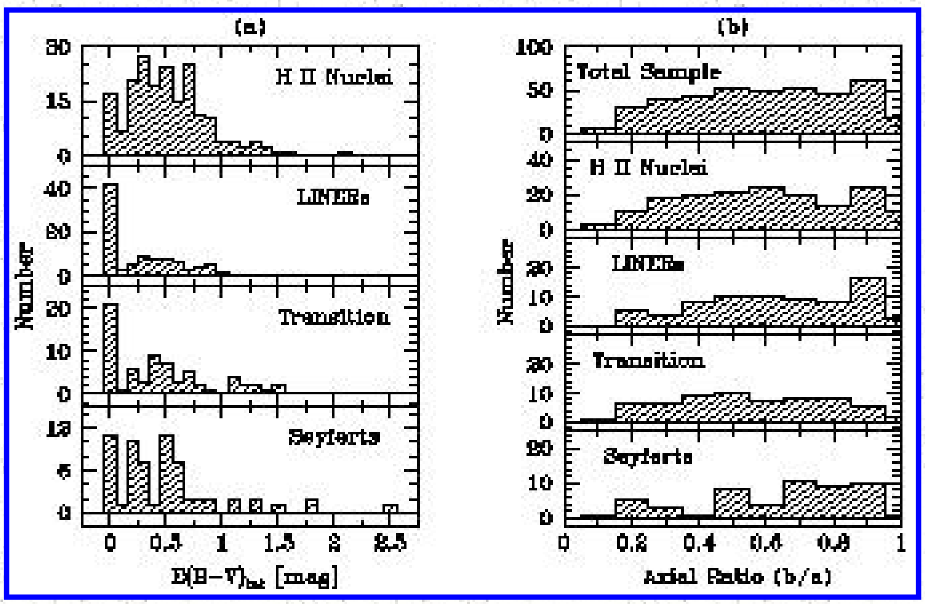

Figure 6. (*a*) Distribution of internal reddening as measured from $H\alpha$ / $H\beta$. (*b*) Distribution of axial ratios (*b/a* = minor-axis diameter/major-axis diameter) taken from de Vaucouleurs et al. (1991); galaxies classified as E, Sdm, Sm, Im, as well as those with highly uncertain classifications, have been excluded.

The axial ratios of H II nuclei and transition objects, on the other hand, appear to be evenly distributed, and do not seem to be affected by any obvious inclination bias. It is tempting to postulate that at least some transition objects are nothing more than highly-inclined LINERs. The increased path length along the line of sight to the nucleus increases the likelihood of intersecting discrete circumnuclear H II regions as well as general extended nebulosity photoionized by massive stars (see also discussion in Section 8).

I note, in passing, that the inclination bias among Seyfert galaxies in our sample is present in Seyfert 1s *and* Seyfert 2s, in agreement with McLeod & Rieke (1995) and Maiolino & Rieke (1995), although in our sample and in that of Maiolino & Rieke the axial-ratio cutoff is not as pronounced as that of the CfA Seyferts studied by McLeod & Rieke. The larger number of high-inclination Seyferts detected compared to the CfA sample probably reflects the much larger average distance of the latter sample. That the absorbing material evidently affects both the broad-line region (BLR) and the NLR implies that the source of obscuration lies in a flat configuration aligned with the plane of the galactic disk. Based on the abrupt fall off of objects with $b/a \lesssim 0.5$ in the CfA sample, McLeod & Rieke argue that the obscuring for the existence of an ``outer torus," whose thickness and radial extent are comparable to the dimensions of the NLR ($r \approx 100$ pc). It is unclear whether this model is applicable to the low-luminosities sources considered here, since opacity from the dusty disk of the galaxies alone can explain the inclination bias observed.

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6.4. *Line Profiles and Kinematics*

The kinematic information contained in line profiles provides unique clues to the LINER puzzle. However, aside from a small handful of relatively crude line width measurements (e.g., Dahari & De Robertis 1988; Whittle 1993, and references therein), little else is known about the line profiles of LINERs as a class. Indeed, with a few exceptions, the FWHM of the forbidden lines in LINERs rarely exceed 500 km s^{-1}, the typical resolution of many of the older surveys. Since the initial study of Heckman (1980b), it has commonly been assumed that the line widths of LINERs are roughly comparable to those of Seyferts (Wilson & Heckman 1985; Whittle 1985, 1993), although Stauffer (1982b) has remarked, admittedly based on very small number statistics, that LINERs seem to have *broader* lines than Seyferts. The study of Phillips et al. (1986), whose spectral resolution is comparable to that of the Palomar survey, also has clearly shown that the typical line widths in LINERs are substantially smaller than what Heckman had first thought.

Let us reexamine some of these issues using the new data set at hand. Despite being blended with Hα most of the time, I will use [N II] λ6583 as the fiducial probe of the velocity field of the NLR, since it is usually the strongest line in the red spectrum, and it is relatively unaffected by stellar absorption. [O III] λ5007 normally is more ideal for measurement of narrow-line profiles, but, in our case, both the S/N and the resolution of the blue spectra are lower than those of the red spectra. The line widths range from being unresolved ($\lesssim$ 115 km s^{-1}) to 500-700 km s^{-1}, with a median value (excluding the first bin, whose values are very uncertain because they are near the resolution limit) of 350, 230, and 290 km s^{-1}, respectively, for LINERs, transition objects, and Seyferts (Fig. 7).

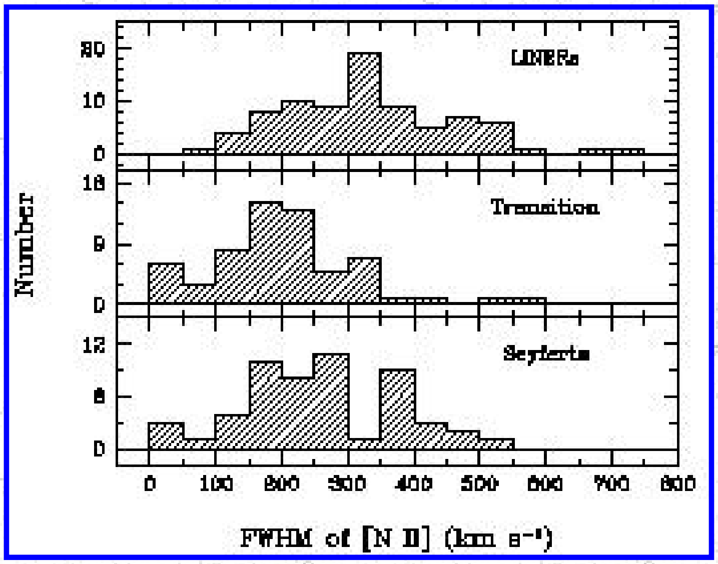

Figure 7. Distribution of FWHM of [N II] λ6583 for 88 LINERs, 62 transition objects, and 55 Seyfert nuclei. The line widths have been corrected for instrumental broadening, and highly uncertain measurements have been excluded.

The characteristic line widths of LINERs reported here are much smaller than those found by Heckman (1980b), and generally consistent with those from other moderate-resolution studies. Not surprisingly, transition objects have narrower lines compared to LINERs; this is to be expected because of the difference in their average Hubble types and the well-known dependence of nebular line width on bulge prominence (e.g., Whittle 1992a, b). What is unexpected is the clear difference evident between LINERs and Seyferts: LINERs have wider forbidden lines than Seyferts, significant at a level greater than 99.999% according to the K-S test.

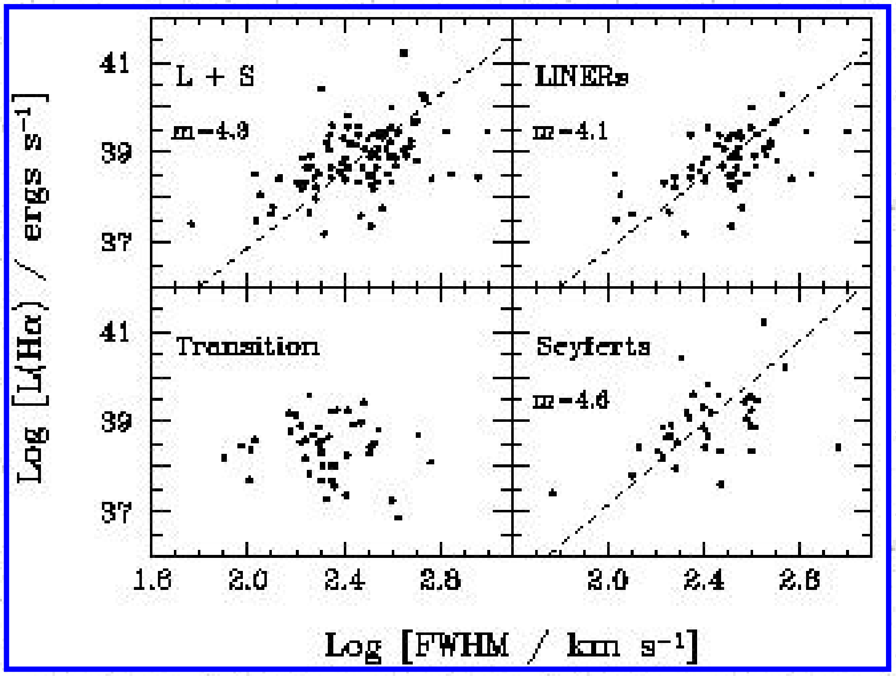

Figure 8. Correlation between Hα luminosity and the FWHM of [N II] λ6583. The line luminosities have been dereddened, and the line widths have been corrected for instrumental resolution.

Since it was first pointed out by Phillips et al. (1983), it has been well established that the luminosities of the forbidden lines in Seyfert nuclei are positively correlated with their widths (Whittle 1985, 1992b). The Seyferts in our sample similarly obey this correlation (Fig. 8), although, interestingly, the slope of the correlation (4.6) is somewhat shallower than that of the more luminous Seyferts in Whittle's (1992b) sample (slope ≈ 5.5). LINERs evidently also obey the correlation, contrary to what Wilson & Heckman (1985) thought; the shallower slope (4.1) reflects the larger line widths found in LINERs. Transition objects, on the other hand, appear not to follow the correlation, although it is likely that the correlation has been partially masked by our inability to completely resolve the narrower lines in this class of objects. The interpretation of the relation between line luminosity and line width has been unclear, mainly because of the existence of other mutual correlations between line width, line luminosity, and radio power (Wilson & Heckman 1985). The recent analysis by Whittle (1992b), however, shows quite convincingly that the fundamental parameter underlying all these correlations is the bulge mass (or central gravitational potential) of the host galaxy.

In light of the dependence of line width on luminosity, it is hardly surprising that the ``typical" Seyfert nucleus has much narrower lines than conventionally assumed. Hence, the criterion for distinguishing Seyfert 2 nuclei from ``normal" emission-line nuclei (i.e., H II nuclei) on the basis of the widths of the narrow lines, either as originally proposed by Weedman (1970, 1977), or as later modified by Balzano & Weedman (1981) and Shuder & Osterbrock (1981), is clearly inappropriate for the majority of the Seyfert galaxy population and should be abandoned.

Keel (1983b) found that in his sample the widths of the forbidden lines are well correlated with galaxy inclination, implying that motion in the plane of galaxy disks dominates the velocity field of the NLR. The present data set does not support this conclusion; no significant correlation between FWHM([N II]) and galaxy axial ratio is seen for any of the subclasses of nuclei, or for all the subclasses added together. Other studies have come to the same conclusion (Heckman et al. 1981; Wilson & Heckman 1985; Whittle 1985; Véron & Véron-Cetty 1986). One can make the inference that either the NLR does not have a disk-like geometry in the plane of the galactic disk, or that the component of the velocity field in the galactic plane contributes only a portion of the total observed line widths (Whittle 1985, 1992a).

Of course, the FWHM is the crudest, first-order characterization of the line profile. Actually, the shapes of the emission lines in most emission-line nuclei, when examined with sufficient spectral resolution (e.g., Heckman et al. 1981; Whittle 1985; Veilleux 1991; Ho et al. 1996f), deviate far from simple analytic functions (such as a Gaussian), often exhibiting weak extended wings and asymmetry. In fact, most Seyfert nuclei have asymmetric narrow lines, and there seems to be a preponderance of blue wings, usually interpreted as evidence of a substantial radial component in the velocity field coupled with a source of dust opacity. It would be highly instructive to see if this trend extends to LINERs, as it could offer insights into possible differences between the NLRs in the two types of objects. These subtleties have never before been examined systematically in LINERs.

The majority of the LINERs in our survey have emission-line spectra of adequate S/N such that possible profile asymmetries (at, say, 20% of the peak intensity) can be discerned (Fig. 9*a*). Among these, ~ 30% are symmetric, ~ 50% have blue asymmetry, and ~ 20% have red asymmetry. Seyferts do not show any obvious differences compared to LINERs, although a much larger proportion of transition objects (~ 60%) are observed to have symmetric line profiles. The latter finding is probably insignificant, since it is more difficult to identify profile asymmetries in objects having narrower lines. From these results, one can conclude that (1) both LINERs and Seyferts seem to exhibit similar trends in their narrow-line asymmetries and that (2) when present, the sense of the asymmetry is preferentially to the blue.

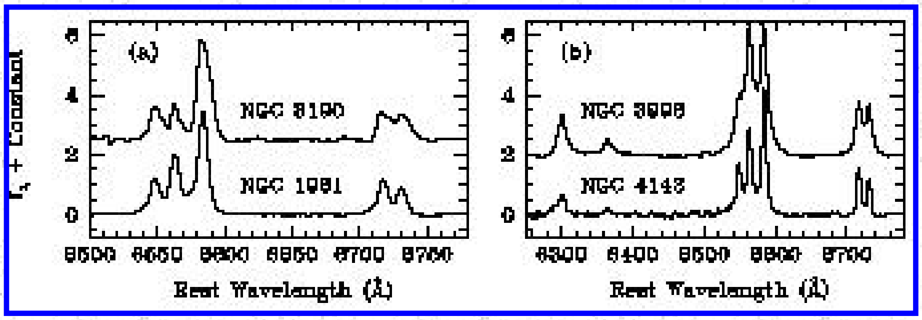

Figure 9. (*a*) Examples of LINERs showing line profiles with blue (NGC 1961) and red (NGC 3190) asymmetry. (*b*) Examples of LINERs having forbidden lines whose widths vary with critical density. Note that in both cases [O I] is broader than [S II].

Detailed studies of Seyferts (e.g., De Robertis & Osterbrock 1984, 1986) and LINERs (Filippenko & Halpern 1984; Filippenko 1985; Filippenko & Sargent 1988; Ho et al. 1993, 1996b) in the past have found that the widths of the forbidden lines correlate positively with their critical densities. This empirical trend has been interpreted as evidence that the NLR contains a wide range of gas densities (10^2-10^7 cm^{-3}), stratified such that the densest material is located closest to the center. In such a picture, [O I] λ6300 ($n_{\rm crit} \approx 10^6$ cm^{-3}) should be *broader* than [S II] $\lambda\lambda$6716, 6731 ($n_{\rm crit} \approx 3 \times 10^3$ cm^{-3}).

Among the objects with securely determined FWHM for [O I] and [S II], approximately 15%-20% of LINERs and 10% of Seyferts show detectable evidence of density stratification in the sense that FWHM([O I]) > FWHM([S II]) (see Fig. 9*b* for examples). In no instance is [O I] ever observed to be narrower than [S II]. However, these numbers need to be interpreted with caution. They do *not* imply that objects failing to show such profile differences do not have density stratification, since a number of effects can conspire to hide this observational signature (Whittle 1985). Furthermore, one's ability to discern such profile differences depends strongly on the S/N of the data (and on the resolution compared with FWHM), and undoubtedly many objects have escaped notice because of this observational selection effect.

Whittle (1985) finds that Seyfert 1 nuclei have a greater likelihood of showing profile differences in their forbidden lines than do Seyfert 2s. The implication is that somehow density stratification in the NLR is directly related to the presence of a BLR. In the present sample, the same trend seems to hold (see also Ho et al. 1993), in that, among those objects with detectable profile differences between [O I] and [S II], ~ 50% of the LINERs and ~ 80% of the Seyferts have broad Hα emission, significantly higher than the respective detection rates of broad Hα in the whole sample (Section 7). But, once again, this result is difficult to evaluate, since selection effects heavily favor the detection of both of these traits in objects having data of high S/N.

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7. SEARCHING FOR BROAD Hα EMISSION

Some LINERs are known to exhibit broad Hα emission (FWHM of a few thousand km s^{-1}), reminiscent of the broad emission lines that define type 1 Seyfert nuclei (Khachikian & Weedman 1974). This subset of LINERs suffers from the least degree of ambiguity in physical origin and can be most safely regarded as representing *genuine* low-luminosity AGNs. These objects are analogous to the so-called intermediate Seyferts (types 1.8 and 1.9) in the terminology of Osterbrock (1981), except that their narrow-line spectra have low ionization and satisfy the definition of LINERs. The luminosities of broad Hα can be orders of magnitude fainter than those in classical Seyfert 1 nuclei. The well-known example of the nucleus of M81 (Peimbert & Torres-Peimbert 1981; Shuder & Osterbrock 1981; Filippenko & Sargent 1988), for example, has a broad Hα luminosity of only 1.8 x 10^{39} ergs s^{-1} (Ho et al. 1996b), and a number of other even less conspicuous cases have been recognized by Filippenko & Sargent (1985).

Searching for broad Hα emission in nearby galaxy nuclei is a nontrivial business, because it entails measurement of a (generally) weak, low-contrast, broad emission feature superposed on a complicated stellar background. Thus, the importance of careful starlight subtraction cannot be overemphasized. Moreover, even if one were able to perfectly remove the starlight, one still has to contend with deblending the Hα + [N II] $\lambda\lambda$6548, 6583 complex. The narrow lines in this complex are often heavily blended together, and rarely do the lines have simple profiles (see Section 6.4). The strategy adopted by Ho et al. (1996f) for the Palomar survey makes use of the line profile of the [S II] $\lambda\lambda$6716, 6731 doublet to model [N II] and the narrow component of Hα.

Some examples of the line decomposition are shown in Figure 10. As was already known from previous studies (Heckman 1980b; Blackman, Wilson, & Ward 1983; Keel 1983b; Filippenko & Sargent 1985), broad Hα is unmistakably present in the LINER NGC 3998 (Fig. 10*a*); the line has FWHM $\approx$ 2150 km s^{-1} and FWZI $\gtrsim$ 5000 km s^{-1} (Ho et al. 1996f). Though much weaker than the component in NGC 3998, a broad component of Hα also seems necessary in order to adequately model the Hα + [N II] complex in NGC 4036 (Fig. 10*b*). Broad Hα emission has long been known to exist in NGC 4579 (Stauffer 1982b; Keel 1983b; Filippenko & Sargent 1985), but its strength is substantially weaker than that deduced by assuming that the narrow lines can be represented by single Gaussians. The extended, asymmetric bases of the [N II] lines, visible in the [S II] doublet, largely account for most of the broad wings in the Hα + [N II] blend (Fig. 10*c*). Finally, I pick NGC 4594 (the Sombrero galaxy; Fig. 10*d*) to illustrate the pitfalls that can potentially afflict data of insufficient S/N or spectral resolution. Judging by the similarity of its Hα + [N II] blend to that of NGC 4579, one might be led to believe that NGC 4594 also has broad Hα emission. However, careful inspection of the line profiles indicates that the [S II] lines have large widths (FWHM $\approx$ 500 km s^{-1}) and extended wings (FWZI $\approx$ 3000 km s^{-1}), and if one assumes that all the narrow lines have identical profiles, no broad Hα component is required to achieve a satisfactory fit in this object. Note that such subtleties would easily have escaped notice in previous surveys.

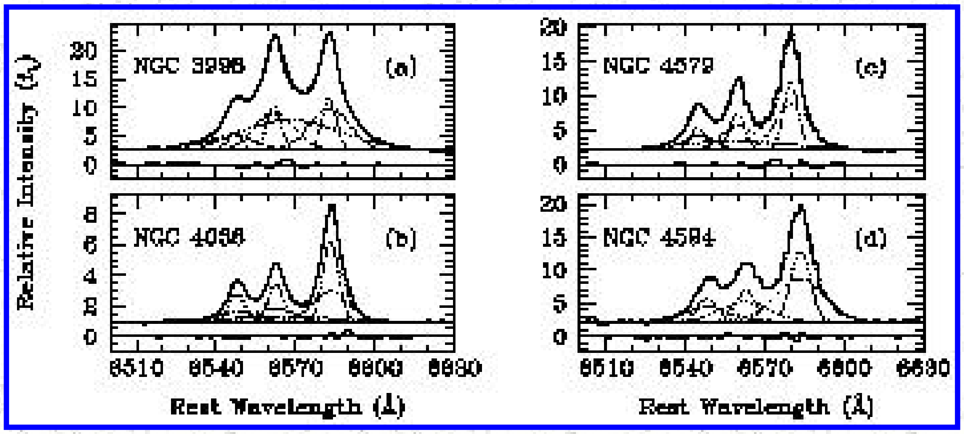

Figure 10. Examples of LINERs with (NGC 3998, 4036, 4579) and without (NGC 4594) broad Hα emission. [N II] $\lambda\lambda$6548, 6583 and the narrow component of Hα are assumed to have the same shape as [S II] $\lambda\lambda$6716, 6731, and the broad component of Hα is specified with a single Gaussian. Residuals of the fit are shown on the bottom of each panel.

Faint broad Hα emission has been discovered or confirmed for the first time in numerous nuclei. The overall statistics of the survey can be summarized as follows: of the 223 emission-line nuclei classified as LINERs, transition objects, and Seyferts, 33 (15%) definitely have broad Hα, and an additional 16 (7%) probably do. Questionable detections were found in another 8 objects (4%). Thus, approximately 20%-25% of all nearby AGNs, corresponding to ~ 10% of all nearby, bright ($B_T \leq$ 12.5 mag) galaxies, can be considered ``Seyfert 1" nuclei, if one adopts the definition that a Seyfert 1 nucleus contains a visible BLR (see Table 3). These numbers, of course, are merely lower limits, since undoubtedly there must exist AGNs with even weaker broad-line emission to which we are insensitive. The fraction of galaxies hosting Seyfert 1 nuclei, therefore, is much higher than previously thought (Weedman 1977; Huchra & Burg 1992; Maiolino & Rieke 1995). Of the 33 objects with definite detections of broad Hα, only 9 are well-known Seyfert 1 nuclei; the majority have substantially lower Hα luminosities and can truly be regarded as ``dwarf" Seyfert 1 nuclei.

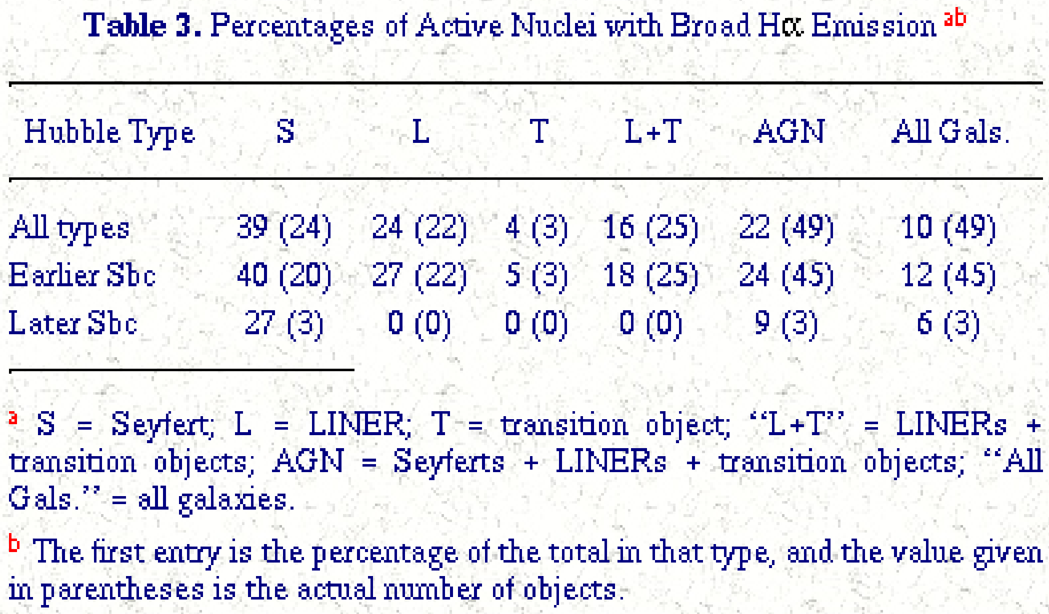

Table 3. Percentages of Active Nuclei with Broad Hα Emission [a][b]

Hubble Type	S	L	T	L+T	AGN	All Gals.
All types	39 (24)	24 (22)	4 (3)	16 (25)	22 (49)	10 (49)
Earlier Sbc	40 (20)	27 (22)	5 (3)	18 (25)	24 (45)	12 (45)
Later Sbc	27 (3)	0 (0)	0 (0)	0 (0)	9 (3)	6 (3)

[a] S = Seyfert; L = LINER; T = transition object; "L+T" = LINERs + transition objects; AGN = Seyferts + LINERs + transition objects; "All Gals." = all galaxies.

[b] The first entry is the percentage of the total in that type, and the value given in parentheses is the actual number of objects.

Excluding previously classified (Véron-Cetty & Véron 1993) Seyfert 1 nuclei (retaining only NGC 4395; Filippenko & Sargent 1989), the broad Hα line of the remaining 40 objects has a median luminosity of ~ 1.2 x 10^{39} ergs s^{-1} and FWHM = 2150 km s^{-1} (Ho et al. 1996f). Five of them have broad Hα luminosities as low as (1-3) x 10^{38} ergs s^{-1}, and the probable detection in NGC 4565, if real, has a luminosity of only 8 x 10^{37} ergs s^{-1}!

It is illuminating to consider the detection rate of broad Hα emission as a function of spectral class (Table 3). Among objects formally classified as Seyferts (according to their narrow-line spectrum), approximately 40% are Seyfert 1s. The implied ratio of Seyfert 1s to Seyfert 2s (1:1.6) has important consequences for several models concerning the evolution and small-scale geometry of AGNs (e.g., Osterbrock & Shaw 1988; Lawrence 1991), but such a discussion is beyond the scope of this paper and will be considered elsewhere. In the present context, of greatest interest is the fraction of LINERs showing broad Hα emission. If we first consider ``pure" LINERs, nearly 25% of them have a BLR. The detection rate among transition objects, however, drops drastically. The cause for this dramatic change is unclear, but a likely explanation is that the broad-line component is simply too weak to be detected in the presence of substantial contamination from the H II region component. Supposing for the moment that the ratio of LINERs with and without BLRs is similar to that in Seyferts, and furthermore that the statistics of the presence of broad Hα in *all* LINERs (i.e., ``pure" LINERs + transition objects) are intrinsically the same as those of ``pure" LINERs, one would conclude that at least 60% of all LINERs are genuine AGNs.

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8. TRANSITION OBJECTS: LINERS IN PARTIAL DISGUISE

Following the suggestion of Ho et al. (1993), I have adopted the working hypothesis that the nuclei classified as transition objects represent composite systems consisting of contributions from both a LINER and an H II region component. Let us now consider this hypothesis in more detail. The physical nature of this subclass of emission-line nuclei has important consequences for the overall demographics of LINERs and AGNs, since numerically these objects rival LINERs (Table 2) (1).

It should come as no surprise that spectra gathered from any fixed-aperture survey will unavoidably integrate spatially distinct regions in some objects, as the physical scale projected by the spectrograph aperture varies with distance. Several examples of composite Seyfert/H II region systems have been recognized in the literature. In cases where the angular extent of the system is sufficiently large, the ``active'' component can be separated from the off-nuclear star-forming component (e.g., Edmunds & Pagel 1982; Véron-Cetty & Véron 1985; Shields & Filippenko 1990). Where only spatially integrated spectra are available, the composite nature has been identified through either decomposition of the line profiles (Véron et al. 1981; Heckman et al. 1983; Kennicutt, Keel, & Blaha 1989) or consideration of the line ratios (Keel 1984; Ho et al. 1993; Boer 1994). The typical distances of the transition objects and LINERs in the Palomar survey, however, are essentially identical. If spatial resolution is the main factor, then an interesting prediction, testable by high-resolution imaging, is that transition objects should show resolved star-forming regions surrounding a central LINER source (unless the star formation occurs in a compact, centrally located cluster). In fact, of the galaxies in the *Hubble Space Telescope (HST)* ultraviolet imaging survey of Maoz et al. (1995; also see Maoz in these proceedings) that show bright emission, three (NGC 4569, NGC 4736, and NGC 5055) have optical spectra resembling those of transition objects (Ho et al. 1996c), and all three exhibit resolved structure in addition to a central core. Although the true nature of the ultraviolet emission can only be assessed through follow-up spectroscopy at comparable angular resolution, its morphology strongly suggests that we are witnessing star formation encircling an active nucleus.

Another intriguing possibility, suggested by the distribution of galaxy axial ratios (Section 6.3), is that transition objects are simply LINERs whose inclinations are such that circumnuclear star-forming regions happen to be projected along the line of sight. Such a scenario favors a geometry in which the star formation in the environment of the nucleus is preferentially confined to a disk-like or ring-like configuration, as appears to be a common situation, especially for galaxies of early Hubble types (Phillips 1996). As the emission-line strengths of LINERs in most instances are in fact weaker than those of giant H II regions, an appropriate mixture of the two components easily accounts for the spectra of transition objects. The average excitation of transition objects, as measured by [O III] / $H\beta$, is lower than that of LINERs. Within the framework discussed here, this finding is to be expected, given the high metal abundance (and hence low excitation) of nuclear H II regions (Ho et al. 1996d).

Distance and orientation effects probably can account for most transition objects, but that cannot be the whole story, since the distributions of Hubble types and absolute luminosity for transition objects are actually slightly different compared to those of LINERs (Fig. 4), in the sense that the former contain some members of later morphological types. If geometry (aperture and inclination effects) alone were the sole determining factor in whether a given nucleus is perceived as a LINER or a transition object, such differences would not be expected. Could it be that some of the transition objects in fact do *not* harbor an AGN (LINER) component? Indeed, models attempting to explain LINERs entirely in terms of stellar photoionization (Filippenko & Terlevich 1992; Shields 1992) succeed best when matched to objects whose [O I] strengths (relative to $H\alpha$) are relatively weak (2). If hot stars alone contribute to the ionization in these sources, and if the stars are not restricted to a centrally unresolved cluster, this alternative model can be tested through high-resolution imaging.

While the composite nature of transition objects demonstrates the spatial and temporal juxtaposition of star formation and the AGN phenomenon, it does *not* imply, much less prove, a direct causal or evolutionary connection between these two disparate physical processes. Stars continuously form at some level in the centers of many galaxies (Ho et al. 1996d), and in early-type spirals, the ``hot-spot'' H II regions can be particularly intense (e.g., Phillips 1996). It has been argued (e.g., Weedman 1983) that the remnants of by-gone massive stars might evolve into a compact configuration at the nucleus, possibly in the form of a single object such as a massive black hole. But until such a scenario can be proven to happen in nature, one must be cautious about unduly ascribing significance to a possibly fortuitous coexistence of two unrelated phenomena.

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[1] Note that the fraction of transition objects is much higher than that given by Ho et al. (1993), whose estimate was based on heterogeneous data taken from the literature. Back.

[2] Objects originally named ``weak-[O I] LINERs'' by Filippenko & Terlevich (1992) and Ho & Filippenko (1993) were renamed ``transition objects'' by Ho et al. (1993). Back.

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9. WHY ARE LINERS WHAT THEY ARE?

There is little doubt, by now, that at least some members of the LINER class truly do belong in the AGN family. LINERs turn out to share a surprisingly large number of traits found in low-luminosity Seyfert nuclei. The global characteristics of their host galaxies (Hubble type, presence of a bar, inclination, and total luminosity), as seen at optical wavelengths at least, are essentially indistinguishable. If the narrow Hα line can be regarded as an approximate gauge of the power output of the central source, it also appears that the luminosity of the nucleus is not a useful predictor of the ionization level. Contrary to a popular misconception, not every weak emission-line nucleus in an early-type galaxy is a LINER; there are plenty of Seyfert nuclei with emission lines just as faint as, if not even fainter than, those seen in LINERs. Judging by the frequency with which asymmetric narrow-line profiles are observed in LINERs, as well as the clear preference for the asymmetry to occur toward the blue half of the line center, the bulk velocity field of the NLRs in LINERs must have a non-negligible radial component, as has been known to be the case in Seyferts. Finally, of great importance, the resemblance between LINERs and Seyferts has now been shown to extend to the presence of a BLR, one of the definitive trademarks of the AGN phenomenon: broad Hα emission is detected in roughly 25% of LINERs.

A continuous, wide range of ionization levels clearly exists among AGNs, and it should be obvious that any clear-cut division of AGNs into ``high" and ``low" excitation flavors is arbitrary at some level. Instead, we should turn our attention to the more general question of what key parameters control the ionization level in AGNs. Whenever possible, I have attempted to broach this issue by referencing the observed properties of LINERs with those of Seyferts, which, for the purposes of this discussion, are implicitly assumed to be a well-understood class of objects. Rudimentary though these comparisons may be, some informative patterns have emerged.

As shown in Section 6, the NLRs in LINERs *differ* from those in Seyferts in several aspects. The line-emitting regions tend to have lower density (at least for the low-density component), lower internal reddening, but larger line widths. Could these indications be telling us something about differences in the structure of the NLR between the two types of objects? An additional clue, although it offers no simple explanation of the above-mentioned observables, is furnished by the apparently higher rate (by about a factor of two) in which density stratification, as identified through profile variations in lines with dissimilar critical densities, is seen in LINERs relative to Seyferts (see Section 6.4).

Whittle (1992a, b) finds that in Seyfert nuclei the widths of the nebular lines of the NLR primarily reflect the gravitational potential of the central region of the host galaxy. He argues that those objects having line velocities that exceed the virial prediction have an additional acceleration mechanism, most likely in the form of radio jets emanating from the nucleus. Do those LINERs whose line widths are larger than those in Seyferts fall in this category? One might further speculate that perhaps shocks generated as a consequence of this ``extra" mechanical energy source really *are* responsible for the spectral differences between this subset of LINERs and Seyferts. If shown to be true, this would be the ultimate vindication for the proponents of shock models (see the review by Dopita in these proceedings)! The conjecture that the NLRs of some LINERs experience additional acceleration from radio jets can be tested with appropriate radio continuum observations. An alternative possibility is that the line width differences actually reflect differences in the central mass concentration. Future models of LINERs need to take all of these factors into consideration.

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10. SUMMARY

The main results presented in this review can be summarized as follows.

1) From a newly completed spectroscopic survey of nearby galaxies, it is confirmed that LINERs are extremely common, being present in about 1/3 of all galaxies with $B_T \lesssim 12.5$ mag. If all LINERs are regarded as active nuclei, they constitute > 70% of the AGN population, and AGNs altogether make up nearly half of all bright galaxies. These statistics should be regarded strictly as lower limits, because very faint AGNs can be hidden by brighter nuclear H II regions, while others deficient in ionized gas may be completely invisible.

2) Approximately half of all LINERs (the so-called transition objects) show evidence in their integrated spectra of contamination by circumnuclear star formation (H II regions). It is argued that the majority of transition objects are not powered exclusively by stellar photoionization.

3) AGNs (transition objects, LINERs, and Seyferts) preferentially occur in early-type galaxies, mostly of Hubble types E-Sbc. The presence of a bar has no visible effect on the probability of a galaxy hosting an AGN or on the level of activity of the AGN, when present.

4) LINERs share a number of similarities with Seyferts, but there are several subtle differences. The host galaxies of both classes of emission-line nuclei have nearly identical distributions of Hubble types, absolute magnitudes, and inclinations angles. The line luminosities and the general properties of the bulk velocity field of their NLRs are also comparable. However, the NLRs of LINERs differ from those of Seyferts in that the densities (in the low-density region) are lower, the reddenings are lower, the line widths are larger, and density stratification may be more common.

5) Based on the relative intensities of the narrow emission lines, at least 10% of all galaxies in the present survey are classified as Seyfert nuclei (types 1 and 2).

6) A BLR, as revealed by the presence of broad (FWHM $\gtrsim$ 2000 km s^{-1}) Hα emission, has been detected in approximately 20%-25% of all nearby AGNs, or in ~ 10% of all galaxies, implying that the space-density of broad-lined AGNs is much higher than previously believed. Some 25% of LINERs show broad Hα emission. If the ratio of LINERs with and without BLRs is assumed to be the same as the ratio of Seyfert 1s to Seyfert 2s (1:1.6), and if the low detection rate of broad Hα emission in transition objects can be attributed to observational selection effects, then at least 60% of all LINERs may be genuine AGNs.

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11. FUTURE DIRECTIONS

As much as observations at other wavelengths are opening new doors to our understanding of LINERs, I hope that this review has persuaded the reader that the more conventional technique of optical spectroscopy still has much to offer. In the same spirit, I will confine my remarks on future work from an optical perspective.

Aside from simple statements concerning the morphological types of the host galaxies of LINERs and Seyferts, one can refine the treatment considerably by considering more quantitative measures of the bulge luminosity. This can be achieved in a straightforward manner from careful bulge/disk decomposition (Kormendy 1977; Boroson 1981), particularly as applied to modern broad-band CCD images. Sizable data bases are rapidly becoming available for many nearby galaxies (e.g., Prieto et al. 1992; de Jong 1996; Frei et al. 1996), but a concerted effort to obtain photometry for the entire Palomar sample would be highly desirable, and such a program is under execution. An even more relevant parameter to consider is the mass of the host galaxy on the relevant scales; for the scale of the bulge and even smaller, this can be accomplished by measuring optical rotation curves in the traditional manner (e.g., Rubin, Whitmore, & Ford 1988).

With the successful identification of the large number of LINERs and low-luminosity AGNs from ground-based surveys, we should now focus on identifying the key parameters in a given galaxy that regulate the level of activity observed. Why do some galaxy nuclei emit such feeble power compared to others? Is the mass of the central object smaller, is the accretion rate (relative to the Eddington rate) curtailed, or perhaps some combination of the two? The amount of gaseous material required to sustain the modest observed luminosities of most nearby AGNs is quite small, being typically much less than 1 $M_{\odot}$ yr^{-1}. Such a fueling rate conceivably can be maintained by mass loss from normal stars (Ho et al. 1996b), and the general interstellar medium from the gaseous disk must also contribute at some level; hence, it appears that the availability of fuel should not be a major factor. It is possible, of course, that the accretion process itself is very inefficient, thereby resulting in a low accretion rate. On the other hand, if the mass of the central object plays the decisive role, then kinematic observations can be used to provide the test. Although high-precision ground-based optical spectroscopy has been used to hunt for massive black holes in the centers of galaxies (Kormendy & Richstone 1995), atmospheric seeing inherently limits the spatial resolution, and the results, although highly suggestive in several instances, are not conclusive. This problem, of course, is tailor-made for *HST*, especially after the installation of the Space Telescope Imaging Spectrograph (STIS).

By analogy with the Seyfert class, in which a continuous sequence of broad-line strength is seen (Osterbrock 1981), LINERs also appear to follow a similar sequence. The relative visibility of the BLR in at least some Seyferts has been successfully interpreted in terms of orientation effects (Antonucci

1993). It seems logical to infer that the same ``unification" picture should extend to the realm of LINERs, unless some crucial element of the model (e.g., the presence or geometry of the obscuring molecular torus) should turn out to depend on the ionization state. It would be highly worthwhile to apply the techniques of optical spectropolarimetry to LINERs, even though the generally low signal levels of these nuclei render such an experiment quite challenging.

The luminosity function of AGNs at the faint end has implications for many fundamental astrophysical problems. Since LINERs constitute the bulk of the AGN population at low luminosities, determining the luminosity function of LINERs is a high priority (this work is in progress).

One obviously hopes to understand the behavior of any class of astronomical objects as a function of time. However, obtaining optical spectra of a representative sample of moderate-redshift galaxies for the identification of emission-line nuclei is a formidable task. The dual need to acquire spectra of at least moderate quality (i.e., suitable for measuring several bright emission lines for classification) for a large sample of galaxies dictates (at the moment) the need for a multi-object spectrograph attached to a large (8-10 m) telescope. As an illustration of the difficulty of such an enterprise, I mention two recent examples from the literature. Lilly et al. (1995, and references therein) used the MOS-SIS spectrograph on the CFHT (3.6 m) to obtain spectra of field galaxies at $< z > \approx 0.6$. Despite integration times of ~ 8 hr, most of their spectra are inadequate for our purposes. Even with the Keck 10 m telescope, moderate-quality spectra of galaxies at intermediate redshifts still require exposure times of ~ 1 hr (Forbes et al. 1996). But despite these difficulties, there is no obvious alternative in the near future. Fortunately, there are several suitable samples of faint galaxies from which to choose. These include the field galaxies selected from the *HST* Medium Deep Survey (Phillips et al. 1995), the $I \leq 22.5$ survey of Lilly et al. (1995), and the Las Campanas redshift survey (Landy et al. 1996, and references therein). Lastly, it should be borne in mind that even under conditions of optimal seeing, 1" at $z = 0.5$ still projects to a linear size of ~ 10 kpc (for $H_0 = 75$ km s^{-1} Mpc^{-1}). At these size scales, the observed spectrum will include substantial contribution from the integrated light of the entire galaxy, and, depending on Hubble type, the signal from the nucleus will be severely diluted. Thus, at intermediate redshifts, only the brightest nuclei will be detected, and one will not be able to quantify the faint end of the luminosity function.

Acknowledgments

The new results presented in this contribution were obtained in collaboration with Alex Filippenko and Wal Sargent and constituted a major portion of my Ph.D. thesis at U. C. Berkeley. I thank them for permission to discuss our work in advance of publication. Alex Filippenko carefully read the manuscript and provided many helpful comments. I am grateful to Anuradha Koratkar for the idea of holding this workshop, to STScI for agreeing to host it, and to the members of the local organizing committee for seeing it to fruition. My research is currently supported by a postdoctoral fellowship from the Harvard-Smithsonian Center for Astrophysics.

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