A SEARCH FOR “DWARF” SEYFERT NUCLEI. V. DEMOGRAPHICS OF NUCLEAR ACTIVITY IN NEARBY GALAXIES

Luis C. Ho1 and Alexei V. Filippenko
Department of Astronomy, University of California, Berkeley, CA 94720-3411

AND

Wallace L. W. Sargent
Palomar Observatory, 105-24 Caltech, Pasadena, CA 91125
Received 1997 January 7; accepted 1997 April 22

ABSTRACT

We use the sample of emission-line nuclei derived from a recently completed optical spectroscopic survey of nearby galaxies to quantify the incidence of local (z ≈ 0) nuclear activity. Particular attention is paid to obtaining accurate measurements of the emission lines and reliable spectral classifications. The resulting database contains the largest collection of star-forming nuclei and active galactic nuclei (AGNs) currently known for nearby galaxies. It consists of 420 emission-line nuclei detected from a nearly complete, magnitude-limited sample of 486 galaxies with B < 12.5 mag and declination greater than 0°; the equivalent width detection limit of the brightest emission line, usually Hβ, is ~0.25 Å.

As is consistent with previous studies, we find detectable amounts of ionized gas in the central few hundred parsecs of most galaxies (86%); emission lines are present in essentially every spiral galaxy and in a large fraction of ellipticals and lenticulars. Based on their narrow-line spectra, half of the objects can be classified as H II or star-forming nuclei and the other half as some form of AGN, of which we distinguish three classes: Seyfert nuclei, low-ionization nuclear emission-line regions (LINERs), and transition objects that we assume to be composite LINER/H II nucleus systems. The population of AGNs is consequently very large; approximately 43% of the galaxies in our survey can be regarded as “active,” although, for a number of reasons, this fraction is still rather uncertain. Most of the objects have much lower luminosities than commonly studied AGNs; the median luminosity of the narrow Hβ line, after correcting for extinction, is only 2 × 10^39 ergs s^-1. Our sample therefore occupies the extreme faint end of the AGN luminosity function.

We detect signatures of a broad-line region, as revealed by visible broad Hβ emission, in ~20% of the AGN sample. Seyfert nuclei, both type 1 and type 2, reside in ~10% of all galaxies. LINERs make up the bulk (~2/3) of the AGN population and a significant fraction (~1/3) of all galaxies. A nonnegligible subset of LINERs emit broad Hβ emission, furnishing direct evidence that a least some LINERs are indeed physically related to the AGN phenomenon.

The dominant ionization mechanism of the nuclear emission depends strongly on the morphological type and luminosity of the host galaxy. AGNs are found predominantly in luminous, early-type (E–Sbc) galaxies, while H II nuclei prefer less luminous, late-type (Sbc and later) systems. The various AGN subclasses have broadly similar host galaxies.

Subject headings: galaxies: active — galaxies: nuclei — galaxies: Seyfert — galaxies: starburst — surveys

1. INTRODUCTION

Emission-line spectroscopy of the central regions of galaxies can yield information that is often inaccessible through other observational techniques. Optical emission lines in particular trace the warm, ionized component of the interstellar medium. In addition to providing information on the nebular conditions and kinematics of the line-emitting material, the emission lines, as reprocessed radiation, can potentially probe the physical mechanism responsible for the ionization of the gas. The presence of optical and ultraviolet emission lines in galaxy nuclei is often taken to be a sign of nuclear “activity,” and spectroscopic surveys, especially at optical wavelengths, have become a widely practiced means of gathering large samples of emission-line nuclei for a variety of statistical studies.

One particular application has been to investigate the nature of the line emission in the central regions of nearby galaxies. Over the last two decades, a number of spectroscopic surveys of nearby galaxies have been conducted for this purpose (Heckman, Balick, & Crane 1980; Heckman 1980b; Stauffer 1982a, 1982b; Keel 1983a, 1983b; Phillips et al. 1986; Véron & Véron-Cetty 1986; Véron-Cetty & Véron 1986). One of the principal results of these studies is the realization that the incidence of nuclear activity, possibly nonstellar in origin, appears to be very high. Heckman (1980b) identified low-ionization nuclear emission-line regions (LINERs) as major constituents of the extragalactic population, particularly among early-type galaxies. The optical emission-line spectra of LINERs broadly resemble those of traditional active galactic nuclei (AGNs) such as Seyfert nuclei, but they have characteristically lower ionization levels. The physical nature of LINERs has been the subject of considerable debate (see Filippenko 1996 for a recent review), but one viable interpretation is that they are simply another manifestation of the AGN phenomenon. If this were true, LINERs would heavily populate the faint end of the local luminosity function of AGNs, with consequences for a range of astrophysical issues. In this paper we assume that LINERs are indeed genuine AGNs.

1 Present address: Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.
Not all emission-line nuclei require an exotic source of ionizing radiation. A sizable fraction of the objects have spectra similar to those of giant extragalactic H II regions, and their primary ionization mechanism must be photoionization by ultraviolet radiation from young, massive stars. This population offers insight into the process of star formation in an environment that is likely to be substantially different from that of galactic disks.

The above-mentioned surveys, while tremendously valuable in establishing the qualitative patterns of nuclear activity among nearby galaxies, suffer from several shortcomings that make quantitative applications uncertain. At optical wavelengths, the nuclear component of a typical nearby galaxy is generally much weaker than the stellar background of its bulge. Thus, in addition to having small fluxes and sometimes being blended together, the emission lines are diluted by stellar absorption lines, necessitating careful removal of the starlight contamination for accurate measurements. As discussed by Ho (1996), this crucial step in the analysis was not always treated adequately in many of the older studies.

We recently completed an extensive spectroscopic study of the nuclear regions of nearly 500 bright northern galaxies. This survey contains the largest published database of homogeneous and high-quality optical spectra of nearby galaxies; it represents a significant improvement, both in sample size and in sensitivity, over previous studies of its kind. We have invested substantial effort in correcting the spectra for starlight contamination in a consistent and objective fashion. In addition to having detected much fainter emission lines than has been possible in the past, we believe that our emission-line measurements are quantitatively much more reliable. This distinction directly impacts the accuracy of the spectral classification, with ramifications for all ensuing analyses that make use of the statistics of the various classes of emission-line nuclei.

The purpose of this paper is to summarize the demographics of emission-line nuclei in light of these new data. Specifically, we report on the detection rates of star-forming nuclei and of various subclasses of AGNs, and we examine the dependence of their detection rates and number distributions on the morphological type and luminosity of the host galaxies. The likely influence of selection biases and sample incompleteness is discussed. Some general statistical properties of the sample are additionally noted.

2. THE PALOMAR SURVEY

The analysis in this paper is based on a magnitude-limited survey of 486 northern galaxies. The sample is defined as being all galaxies listed in the Revised Shapley-Ames Catalog of Bright Galaxies (RSA; Sandage & Tammann 1981) with $\delta > 0^\circ$ and $B_T \leq 12.5$ mag, with a few minor alterations as described by Ho, Filippenko, & Sargent (1995, hereafter Paper II). The database consists of high-quality optical spectra of moderate resolution ($100-200 \text{ km s}^{-1}$) acquired with the Hale 5 m telescope at Palomar Observatory (Filippenko & Sargent 1985, hereafter Paper I). The selection criteria of the survey ensure that the sample is a fair representation of the local ($z \approx 0$) galaxy population, at least for high surface brightness systems, and the proximity of the objects enables fairly good spatial resolution to be achieved. We employed a long slit of width 2$^\prime$ and adopted an extraction width of 4$^\prime$, which projects to an aperture with linear dimensions $\sim 200 \times 400 \text{ pc}^2$ for the typical distances of the sample galaxies (18 Mpc; Table 1).\(^2\) Paper II presents the spectral atlas of the survey and discusses the observational parameters and data reduction; Paper III (Ho, Filippenko, & Sargent 1997a) gives the line measurements, object classifications, and details of our treatment of starlight subtraction; Paper IV (Ho et al. 1997e) highlights the nuclei showing broad Hz emission; and Paper VI (Ho, Filippenko, & Sargent 1997b) provides a comparative analysis of the various AGN subclasses. Additional papers in this series (Ho, Filippenko, & Sargent 1997c, 1997d) analyze the subsamples of star-forming nuclei and barred galaxies. All quantities used in this study are drawn from Paper III.

The classification system used throughout our survey parallels closely the methodology of Veilleux & Osterbrock (1987). As explained in Paper III, this system adopts a set of spectroscopic criteria that depends entirely on the line-intensity ratios of several prominent, narrow, optical emission lines. We distinguish four subclasses of emission-line nuclei: H II nuclei, Seyfert nuclei, LINERs, and transition objects. H II nuclei have spectra closely resembling those of H II regions and therefore are assumed to be powered through photoionization by young, massive stars. The other three groups represent variants of AGNs. The composite characteristics of the spectra of transition objects suggest that they are LINER nuclei contaminated by emission from neighboring H II regions (Ho, Filippenko, & Sargent 1993; Ho 1996). This hypothesis is explored further in Paper VI, where we demonstrate that transition objects and regular LINERs have strikingly similar global and nuclear properties, suggesting that they share a common physical origin. However, it should be borne in mind that the available data

\(^2\) We adopt $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ in this series of papers.

---

TABLE 1

| Spectral Class       | No. (mag) | $B_T$ (mag) | $M_0^\alpha$ (mag) | $M_0^\beta$ (mag) | $d$ (Mpc) | $i$ (deg) | $L(Hz)$ (ergs s$^{-1}$) | $\text{EW}(H\alpha$) (Å) |
|---------------------|-----------|-------------|--------------------|--------------------|-----------|-----------|------------------------|---------------------|
| All galaxies        | 486       | 11.90       | 486                | 20.15              | 401       | 52.0      | ...                    | ...                 |
| All emission        | 417       | 11.89       | 417                | 20.22              | 361       | 52.0      | 329                    | 39.11               |
| H II nuclei         | 206       | 12.03       | 206                | 20.01              | 190       | 53.5      | 172                    | 39.25               |
| All AGNs            | 211       | 11.73       | 211                | 20.46              | 171       | 51.0      | 157                    | 38.93               |
| Pure LINERs         | 94        | 11.72       | 94                 | 20.46              | 72        | 50.0      | 71                     | 38.82               |
| Transition objects  | 65        | 11.72       | 65                 | 20.26              | 55        | 58.0      | 48                     | 38.84               |
| All LINERs          | 159       | 11.72       | 159                | 20.38              | 127       | 52.0      | 119                    | 38.82               |
| Seyfert nuclei      | 52        | 11.77       | 52                 | 20.73              | 44        | 44.5      | 38                     | 39.22               |

\(a\) Excluding $T = "\ldots\"$, 90, and 99 (see Paper III).
cannot yet unambiguously exclude alternative explanations that do not invoke nonstellar processes. In the following discussion, we will explicitly assume that transition objects indeed contain LINER nuclei, and hence that they are AGNs, although we will point out how the results would be affected if this assumption were to be relaxed. When there is a need to distinguish regular LINERs from composite sources, we will refer to the former as "pure LINERs" and the latter as "transition objects".

### TABLE 2A

**Detection Rates of Emission-Line Nuclei**

| Hubble Type   | All Classes | Pure Absorption Nuclei | Emission Nuclei | H II Nuclei | Seyfert Nuclei |
|---------------|-------------|------------------------|-----------------|-------------|----------------|
|               | No. | $P_e$ | No. | $P_i$ | $P_e$ | No. | $P_i$ | $P_e$ | No. | $P_i$ | $P_e$ | No. | $P_i$ | $P_e$ |
| E             | 57   | 11.7 | 26 | 45.6 | 39.4 | 31 | 54.4 | 7.4 | 0 | 0.0 | 0.0 | 4 | 7.0 | 7.7 |
| S0            | 88   | 18.1 | 32 | 36.4 | 48.5 | 56 | 63.6 | 13.3 | 7 | 7.9 | 3.4 | 10 | 11.4 | 19.2 |
| S0/a-Sab      | 77   | 15.8 | 5 | 6.5 | 7.6 | 72 | 93.5 | 17.1 | 17 | 22.1 | 8.3 | 14 | 18.1 | 26.9 |
| Sb-Sbc        | 103  | 21.2 | 1 | 1.0 | 1.5 | 102 | 99.0 | 24.3 | 52 | 50.5 | 25.2 | 15 | 14.5 | 28.9 |
| Sc-Scd        | 109  | 22.4 | 1 | 1.0 | 1.5 | 108 | 99.0 | 25.7 | 89 | 81.7 | 43.1 | 6 | 5.5 | 11.5 |
| Sd-Sdm        | 19   | 3.9  | 1 | 5.3 | 1.5 | 18 | 94.7 | 4.3 | 15 | 78.9 | 7.3 | 1 | 5.3 | 1.9 |
| Sm-Im         | 21   | 4.3  | 0 | 0.0 | 0.0 | 21 | 100.0 | 5.0 | 17 | 80.9 | 8.3 | 1 | 4.8 | 1.9 |
| I0            | 5    | 1.0  | 0 | 0.0 | 0.0 | 5 | 100.0 | 1.2 | 3 | 60.0 | 1.5 | 0 | 0.0 | 0.0 |
| Pec + S pec   | 7    | 1.4  | 0 | 0.0 | 0.0 | 7 | 100.0 | 1.7 | 6 | 85.7 | 2.9 | 1 | 14.3 | 1.9 |
| All           | 486  | 100.0 | 66 | 13.6 | 100.0 | 420 | 86.4 | 100.0 | 206 | 42.4 | 100.0 | 52 | 10.7 | 100.0 |

### TABLE 2B

**Detection Rates of Emission-Line Nuclei**

| Hubble Type   | LINERS | Transition Objects | LINERS + Transition | All AGNs | Type 1 AGNs |
|---------------|--------|--------------------|---------------------|----------|-------------|
|               | No. | $P_e$ | No. | $P_i$ | $P_e$ | No. | $P_i$ | $P_e$ | No. | $P_i$ | $P_e$ | No. | $P_i$ | $P_e$ |
| E             | 21   | 36.8 | 22.3 | 5 | 8.8 | 7.7 | 26 | 45.6 | 16.3 | 30 | 52.6 | 14.2 | 7 | 12.3 | 15.2 |
| S0            | 23   | 26.1 | 24.5 | 16 | 18.2 | 24.6 | 39 | 44.3 | 24.5 | 49 | 55.7 | 25.2 | 9 | 10.2 | 19.6 |
| S0/a-Sab      | 28   | 36.4 | 29.8 | 13 | 16.9 | 20.0 | 41 | 53.3 | 25.8 | 55 | 71.4 | 26.1 | 16 | 20.8 | 34.8 |
| Sb-Sbc        | 12   | 11.7 | 12.8 | 23 | 22.3 | 35.4 | 35 | 33.9 | 22.0 | 50 | 48.5 | 23.7 | 10 | 9.7 | 21.7 |
| Sc-Scd        | 7    | 6.4  | 7.5 | 5 | 4.6 | 7.7 | 12 | 11.0 | 7.6 | 18 | 16.5 | 8.5 | 2 | 1.8 | 4.4 |
| Sd-Sdm        | 0    | 0.0  | 0.0 | 2 | 10.5 | 3.0 | 2 | 10.5 | 1.3 | 3 | 15.8 | 1.4 | 0 | 0.0 | 0.0 |
| Sm-Im         | 1    | 4.8  | 1.1 | 1 | 4.8 | 1.5 | 2 | 9.5 | 1.3 | 3 | 14.3 | 1.4 | 1 | 4.8 | 2.2 |
| I0            | 2    | 40.0 | 2.1 | 0 | 0.0 | 0.0 | 2 | 40.0 | 1.3 | 2 | 40.0 | 0.9 | 0 | 0.0 | 0.0 |
| Pec + S pec   | 0    | 0.0  | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 1 | 14.3 | 0.5 | 1 | 14.3 | 2.2 |
| All           | 94   | 19.3 | 100.0 | 65 | 13.4 | 100.0 | 159 | 32.7 | 100.0 | 211 | 43.4 | 100.0 | 46 | 9.5 | 100.0 |

Note—$P_e$ is the percentage of all galaxies of a given Hubble type belonging to a specific spectroscopic class. $P_i$ denotes the percentage of all galaxies of a given spectroscopic class belonging to a specific Hubble type. The sum of all values of $P_i$ in a given class totals 100%. The group "All AGNs" represents the sum of Seyferts, LINERs, and transition objects, and "Type 1 AGNs" refers to all AGNs found to have broad Hα emission in Paper IV.
to the combined sample of pure LINERs and transition objects as “all LINERs.” Finally, all three classes of AGNs can host a broad-line region, as evidenced by the presence of broad Hα emission (Paper IV). Following the convention of Papers III and IV, we extend the “type 1” and “type 2” designations of Seyfert galaxies (Khachikian & Weedman 1974) to include LINERs and transition objects.

3. DETECTION RATES OF EMISSION-LINE NUCLEI

The incidence of emission-line nuclei is very high in our sample (Table 2 and top panel of Fig. 1a). Integrated over all Hubble types, 86% of the nuclei have emission lines down to an equivalent width detection limit of ~0.25 Å (3σ). The detection rate among spirals alone is even higher: essentially all (98%) of the galaxies classified as S0/a and later have emission-line nuclei, as opposed to 54% of ellipticals and 64% of lenticulars. Among the group of 66 galaxies with pure absorption-line spectra, only eight are not classified as ellipticals or lenticulars. In a sample of disk systems with Hubble types ranging from S0/a to Scd, but with a brighter limiting magnitude (B < 12.0 mag), Keel (1983a) also found that essentially every object has detectable emission lines within an 8” circular aperture. Because the sensitivity of the Palomar survey is much higher than that of Keel, we are able to achieve a comparably high detection rate for this range of morphological types, even though our effective aperture (8 arcsec2) is 6 times smaller and our survey limit fainter. The Hubble-type distributions of the surveys of Heckman et al. (1980) and Véron-Cetty & Véron (1986) match that of the present sample more closely, and in these the detection rate was only ~60%–65%. The near-ubiquity of emission lines in the nuclear spectra implies that the central 200–400 pc of most galaxies, including those of early type, contain detectable amounts of warm (~104 K) ionized gas. The typical Hα luminosity of ~1 × 10^19 ergs s^-1 (§6) and electron density of 200 cm^-3 (Paper VI; Ho et al. 1997c) translate to an ionized hydrogen mass of ~2 × 10^5 M⊙.

The two categories of nuclear activity (stellar and nonstellar) occur with nearly equal frequency among galaxy nuclei. Approximately half of the emission-line objects (42% of all galaxies) are classified as H II nuclei, and the other half belong to the AGN group (43% of all galaxies); the proportion becomes 56% H II nuclei and 30% AGNs if we reassign transition objects to the former group. While the incidence of both varieties of nuclear activity is widespread among galaxies of all morphologies, each depends strongly and differentially on the Hubble type of the host (Fig. 1a, middle and bottom panels). H II nuclei clearly prefer late-type hosts, whereas AGNs prefer early-type hosts. Some overlap occurs between the two distributions, but they segregate roughly at a Hubble type of Sbc: 82% of galaxies later than Sbc have H II nuclei, and 60% of galaxies earlier than Sbc have AGNs. Surprisingly, not a single elliptical galaxy in our sample shows detectable nuclear emission attributable to star formation, in stark contrast to the substantial fraction of AGNs that contribute to this morphological bin (~50%). This is consistent with the survey of early-type (E and SO) galaxies of Phillips et al. (1986); the few objects they identified as having H II nuclei are all classified SO (two are E–SO). Signatures of nonstellar ionization, on the other hand, do exist in a minority of late-type hosts; roughly 15% of the Sc, Sd, and Sm galaxies and 40% of the amorphous systems (I0) contain AGNs (but there are only five amorphous galaxies in our sample, so the latter statistic should be treated with caution).

4. SUBCLASSES OF ACTIVE GALACTIC NUCLEI

All three subclasses of AGNs show similar detection rates as a function of Hubble type (Fig. 1b). The most conspicuous differences are that (1) pure LINERs, compared to Seyferts, are seen in a higher fraction of ellipticals, and (2) among all LINERs, the transition group is detected more frequently in galaxies of somewhat later Hubble types. Approximately 10% of the survey sample contain Seyfert nuclei; this doubles the figures estimated in previous studies (Stauffer 1982b; Keel 1983b; Phillips, Charles, & Baldwin 1983; Maiolino & Rieke 1995). Note that the Seyfert nuclei in our sample do not exclusively reside in spirals, as is usually thought (e.g., Adams 1977; Weedman 1977). Pure LINERs are present in ~19% of all galaxies, and transition objects, which by assumption also contain a LINER component, account for another ~13%. Thus, LINERs are major constituents of the galaxy population—they reside in one-third of all galaxies brighter than Bp = 12.5 mag. Because their presence strongly coincides with early-type hosts, their detection rate approaches 50% for galaxies of types E–Sbc. If all LINERs can be regarded as genuine AGNs, they make up the bulk of the AGN population (75%) in the luminosity range probed by our survey, out-numbering Seyferts 2:1.

A sizable fraction of the AGN sample (~20%) show broad Hα emission, presumably arising from the conventional broad-line region (Paper IV). The broad emission is generally very weak and difficult to measure; consequently, most of the objects identified in our survey have previously been unrecognized. Of the 46 detections reported in Paper IV, only 22 have a formal Seyfert classification, and the remaining 24 (22 LINERs and two transition objects) fall into the LINER group. We proposed in Paper IV that the “type 1” and “type 2” designations, traditionally used to distinguish between Seyfert nuclei with and without a visible broad-line region, respectively, be extended to include LINERs and transition objects. The number ratio of type 2 to type 1 Seyferts in our survey is 1.4:1; the corresponding ratio for pure LINERs is 3.3:1, and for all LINERs (including transition objects) it is 5.6:1. As discussed in Paper IV, we suspect that selection effects severely hamper the detection of broad Hα in transition objects, thereby leading to an apparently low incidence of type 1 objects in this group. It is possible that the true frequency of type 1 transition objects is as high as that of type 1 pure LINERs.

5. TRENDS WITH GALAXY MORPHOLOGICAL TYPE AND INTEGRATED LUMINOSITY

The distribution of morphological types in Figure 2a illustrates that H II nuclei reside most frequently in Sc galaxies (median T = 5.0, where T is the numerical Hubble type index as defined by de Vaucouleurs 1959, 1963), and most AGNs cluster toward early-type disk systems (S0–Sbc; median T = 1.0, corresponding to Sa). The three AGN subclasses once again show very similar distributions of host galaxy types (Fig. 2b). LINERs and Seyferts have virtually indistinguishable host galaxy types (aside from a higher proportion of ellipticals among LINERs), an important clue to the physical nature of LINERs (Paper VI).
The frequency of bars among the emission-line objects is identical to that of the entire sample of disk systems in the survey (56%; Paper III), since most of the absorption-line objects are ellipticals. The bar fraction of the H II nuclei hosts (62%) does not differ appreciably from that of the AGN hosts (49%), which itself remains constant among the AGN subclasses. However, as discussed more fully by Ho et al. (1997d), the presence of a bar does enhance the probability and intensity of nuclear star formation in spiral galaxies. Such an effect is not seen among the AGN hosts.

Because early-type galaxies on average tend to be more luminous than late-type galaxies (see Roberts & Haynes 1994), the trends perceived with Hubble type translate into similar patterns in total galaxy luminosity. The distributions of absolute blue magnitudes, corrected for internal extinction ($M_{B_{r}}^*$; Paper III), are shown in Figure 3a. The hosts of H II nuclei clearly have lower luminosities than the hosts of AGNs, being fainter than the latter by $\sim 0.5$ mag in their median $M_{B_{r}}^*$ ($-20.01$ mag vs. $-20.46$ mag). The cumulative distributions of the two samples are significantly different, according to the Kolmogorov-Smirnov test (Press et al. 1986); the probability that the two distributions are drawn from the same population ($P_{KS}$) is $5.7 \times 10^{-4}$.

Interestingly, the objects lacking emission-line nuclei are noticeably less luminous (median $M_{B_{r}}^* = -19.56$ mag) than those containing either H II nuclei or AGNs. Since almost
Fig. 4.—Distribution of equivalent widths of the narrow Hα emission line for all emission-line nuclei, H II nuclei, and AGNs. The bins are separated by 2 Å, and the last bin contains all objects with EW(Hα) > 30 Å.

Fig. 5.—Distribution of luminosities of the narrow Hα emission line for all emission-line nuclei, H II nuclei, and AGNs. The luminosities in the shaded and solid histograms were corrected for Galactic and internal reddening, the latter determined from the observed Balmer decrement (see Paper III), while the observed luminosities are shown in the unshaded histogram with a heavy line. The bins are separated by 0.25 in logarithmic units.

Fig. 6.—Distribution of equivalent widths of the narrow Hα emission line as a function of (a) the numerical Hubble type index T and (b) the total absolute blue magnitude of the galaxy, $M^0_{B_v}$. The numerical indices have the following correspondence to the Hubble sequence (see Table 13 of Paper III): $-5 = E0$, $-3 = S0$, $1 = Sa$, $3 = Sb$, $5 = Sc$, $7 = Sd$, $10 = Im$, $90 = I0$, and $99 = Pec$ or S pec. The typical uncertainty in the line measurement is illustrated by the vertical bar in the lower right-hand corner.
again noteworthy that LINERs and Seyferts both peak at $M_B^* \approx -20.5$ mag, about 0.4 mag brighter than $M_B^{*\text{BT}}$, the typical absolute magnitude of the field-galaxy luminosity function (see Kirshner, Oemler, & Schechter after Kirshner, 1979).

### 6. STRENGTHS OF THE EMISSION LINES

Although the emission-line properties of the AGN and H II–nucleus samples are discussed in separate publications (Paper VI; Ho et al. 1997c), here we will comment briefly on the strengths of the emission lines. In general, the line emission of the objects in the Palomar survey is quite feeble. A wide range of equivalent widths is found, but the median value for the Hα line is only 5 Å (Fig. 4). H II nuclei have significantly higher emission-line equivalent widths than AGNs [median EW(Hα) = 18 Å vs. 2 Å]. The marked contrast in equivalent widths between the two classes of nuclei arises not out of intrinsic luminosity differences, but rather out of the great disparity between the nuclear (stellar) continuum strengths of the two types of host galaxies. Late-type galaxies, the preferred hosts of H II nuclei, have fainter, smaller bulges than early-type galaxies, the dominant hosts of AGNs. The extinction-corrected Hα luminosities of H II nuclei are in fact larger than those of the AGN sample (Fig. 5), but the difference is only a factor of 2 [median $L(H\alpha) = 1.8 \times 10^{39}$ ergs s$^{-1}$ vs. $8.5 \times 10^{38}$ ergs s$^{-1}$], whereas the difference in the equivalent widths of the two groups amounts to a factor of 9. The variation of the emission-line equivalent width with galaxy type and luminosity is illustrated in Figure 6, where the steady rise of the relative line strength when approaching galaxies with later Hubble types and lower luminosities is quite apparent. By contrast, the line luminosity actually decreases in late-type and low-luminosity galaxies (Fig. 7).

The majority of the H II nuclei in our survey are experiencing only modest levels of current star formation. Indeed, the typical Hα luminosity does not greatly exceed that of many individual giant H II regions, and the inferred current star formation rates certainly are not unusual. Thus, we have resisted calling these objects “starburst” nuclei like those of Balzano (1983). Similarly, the AGNs considered here have unspectacular luminosities when compared to traditionally studied Seyferts such as those selected from the Markarian survey. The Seyferts in the compilation of Dahari & De Robertis (1988), for instance, have typical line luminosities ranging from 2 to 3 orders of magnitude larger than those in our survey. Our sample therefore contains mainly low-luminosity or “dwarf” AGNs.

### 7. COMPLETENESS AND SELECTION EFFECTS

The completeness of the Palomar survey overall is very close to that of a sample limited to $B_T \leq 12.5$ mag in the RSA, from which our sample was drawn. A discussion of the completeness of the RSA can be found in Sandage, Tammann, & Yahil (1979). Here we wish to consider the completeness of the different types of emission-line objects with respect to the parent population. A simple way to examine this issue is to compare the distribution of apparent magnitudes of the different subsamples with that of the parent sample. From Figure 8a, it is evident that the parent sample and the sample of H II nucleus hosts have very similar distributions of $B_T$ ($P_{KS} = 0.13$), indicating that the latter is not incomplete relative to the former. The AGN sample, on the other hand, has a marginally brighter $B_T$ distribution than the parent sample ($P_{KS} = 0.043$). This arises not because the AGN sample has, on average, smaller distances (see below), but rather because it is mainly comprised of more luminous, early-type galaxies (§5). The AGN sample therefore suffers from some incompleteness with respect to the parent sample, although the effect seems to be slight. On closer inspection, it appears that most of the difference can be attributed to the group of pure LINERs alone (Fig. 8b).

To assess how the detection rates presented thus far would be modified by the relative incompleteness of the different types of nuclei, we chose subsamples with various brighter apparent magnitude limits from the parent sample, recomputed the detection rate of each group of emission-line objects, and calculated the Kolmogorov-Smirnov statistic to gauge the change in completeness levels. This experiment showed that all the emission-line groups become complete with respect to the new parent sub-
samples at $B_T \approx 12.2$ to $12.3$ mag—that is to say, there is no statistically significant difference ($P_{KS} > 0.1$) in the relative distributions of $B_T$. The detection rates of the various types of emission-line nuclei at this new limiting magnitude, however, hardly change from those found using the original limiting magnitude. The detection rate for AGNs, and similarly for LINERs and transition objects, increases by about 10%, that of H II nuclei decreases by the same amount, and that of Seyferts remains essentially unaltered.

Because our data were acquired using a slit of fixed angular size, the physical dimensions of the projected aperture scale linearly with the distance of the object, and distance-dependent selection biases can affect our measurements in principle. Specifically, with regard to the detection rates under consideration, two kinds of selection effects can occur. First, the detection of any line emission, regardless of its character, obviously depends on the angular dimension of the emission compared to the aperture size. For a given (low) surface brightness, the emitting material can be undetectable if it is very extended compared to the aperture—for example, if the galaxy is exceptionally nearby. The object would then be considered to be lacking emission lines, even though it would have been recognized as an emission-line nucleus had it been placed at a distance more typical of the rest of the sample. An interesting example is M31. We failed to detect any line emission in the spectrum of its nucleus because of its proximity (0.75 Mpc), and in we classified it as an absorption-line nucleus. However, line emission of low surface brightness, extending over scales of several hundred parsecs, does exist in the circumnuclear regions of M31 & Ford Moreover, (Rubin 1971). Ciardullo et al. have shown that the spectrum of the gas shows enhanced [N II] $\lambda\lambda 6548, 6583$ and [S II] $\lambda\lambda 6716, 6731$ emission, as is typical of most AGNs (see Paper III). Heckman (1996) recently concluded that the spectrum is that of a LINER. The effect of distance, however, has a negligible bearing on our results because the absorption-line sample does not have a smaller median distance than the emission-line sample, and because the detection rate of emission-line objects is already so high (86%) that there is not much room for error.

Perhaps more worrisome is the accuracy of the relative detection rates among the emission-line objects. The integrated spectrum of the central region of a distant galaxy has a higher likelihood of being contaminated by circumnuclear H II regions than a nearby one, thereby potentially biasing the AGN detection rate toward lower values among distant galaxies. However, the distributions of distances show no gross differences for the various subclasses (Figs. 9a and 9b). The H II nuclei are on average closer than the AGNs (median distance 17.1 Mpc vs. 20.6 Mpc; $P_{KS} = 2.6 \times 10^{-4}$) as a result of having lower luminosity hosts, and LINERs (both including and excluding transition objects) are marginally more distant than Seyferts (by 1–2 Mpc). In any case, it seems unlikely that such small differences in distance can lead to significant misclassifications in the mean. We reached a similar conclusion in Paper III, based on the analysis of the variation of the [N II] $\lambda 6583$/$\lambda 5100$ ratio with distance. Any individual object, of course, can certainly still be affected. We mentioned the case of M31 above; Rubin & Ford (1986) discussed a similar situation for the nucleus of M33.

Finally, in Figure 10 we examine the inclination angles ($i$) of the disk systems. The distribution of cosine $i$ should be flat for an unbiased sample with random orientations. As discussed in Paper III, there is a deficit of edge-on systems ($i \geq 70^\circ$) in the parent sample, and this behavior is characteristic of magnitude-limited samples. Again, what is of interest here is to see whether there are any differences between the total sample and each of the separate groups, as well as among the groups. None of the subsamples, with the exception of the Seyferts, shows statistically different distributions of cosine $i$, compared to the total sample. Seyferts do show a marginally significant deficit of edge-on
systems ($P_{KS} = 0.047$), and they are also somewhat more face-on than the combined LINER sample ($P_{KS} = 0.060$). Another subtle difference is that transition objects tend to be more edge-on than pure LINERs ($P_{KS} = 0.064$). Although these differences are not large, they are of relevance in understanding the physical distinctions between the AGN subclasses, and we will reconsider them in Paper VI. But for now, we simply note that selection biases due to inclination effects do not appear to be serious.

In summary, we consider the detection rates reported in Table 2 and Figure 1, in both absolute and relative numbers, to be largely uncorrupted by incompleteness introduced either by the magnitude limit of the survey or by selection effects due to distance or inclination angle.

8. COMPARISON WITH PREVIOUS STUDIES

Many of the findings from the Palomar survey presented here are qualitatively similar to results from the older surveys cited in § 1. It has long been recognized that the incidence of nuclear activity, especially as evidenced by the LINER phenomenon, is widespread in the nearby galaxy population. Although it is still unclear whether all LINERs can be unequivocally associated with AGNs (Paper VI), the general consensus has been that these objects must be related to some form of activity substantially different from "normal" star formation. Furthermore, it has occasionally been pointed out that galaxies hosting H II nuclei have quite different morphological types than those containing Seyfert

![Fig. 9a](image1)

![Fig. 9b](image2)

Fig. 9.—Distribution of distances for (a) all sample galaxies, H II nuclei, and AGNs and (b) the different classes of AGNs. The bins are separated by 5 Mpc.

![Fig. 10a](image3)

![Fig. 10b](image4)

Fig. 10.—Distribution of the cosine of the inclination angle for (a) all sample galaxies, H II nuclei, and AGNs and (b) the different classes of AGNs. The bins are separated by 0.1.
or LINER nuclei (e.g., Heckman 1980a; Keel 1983a; Terlevich, Melnick, & Moles 1987; Pogge 1989). Indeed, Burbidge & Burbidge (1962) drew attention to the fact that some galaxies show abnormal strengths of [N II] λ6583 compared to Hα, and they noted that such galaxies tend to be of early type.

As discussed in § 1, the Palomar survey has greater sensitivity to weak emission lines than previous surveys of this kind. From a statistical point of view, it also contains a larger number of galaxies as well as a wider range of morphological types (see the summary of old surveys presented in Table 1 of Ho 1996). More importantly, however, we believe our emission-line measurements, and hence all subsequent derivations, to be quantitatively much more reliable. Our spectral classification in particular should be considerably more secure. The increased accuracy largely stems from our treatment of starlight correction. As an example of the immediate benefits to be gained, note that previous studies were rarely able to detect the weak but diagnostically important line [O I] λ6300. Our ability not only to detect but also to measure [O I] in a significant fraction of our emission-line objects (81%) has let us recognize the class of sources we call transition objects. Furthermore, having access to a wider wavelength range, particularly in the blue, allows us to specify the classification better. The surveys of Keel (1983a, 1983b) and Phillips et al. (1986), for instance, did not include the Hβ and [O III] λλ4959, 5007 lines, so they had no information on the excitation of their emission-line objects, and therefore no way of distinguishing between Seyferts and LINERs. Perhaps the most dramatic improvement, however, can be in the high detection rate of broad Hα emission in our survey (Paper IV). This has resulted in a robust determination of the relative fraction of type 1 and type 2 AGNs, and it has shown, for the first time, that a significant fraction of LINERs contain a broad-line region, a finding that has important consequences for the longstanding debate on the physical origin of this class of objects (Paper VI).

As is well known, existing AGN samples suffer from various degrees of bias and incompleteness (see, e.g., discussion in Huchra & Burg 1992). The incompleteness is most severe for low-luminosity sources. The sample of Seyfert nuclei spectroscopically selected from the CfA redshift survey (Huchra & Burg 1992) is widely regarded as being the least biased set available. Yet even this sample misses many of the weak sources included in the Palomar list, and, as recognized by Huchra & Burg (1992), the CfA sample is very incomplete in its census of LINERs. Maiolino & Rieke (1995) improved the situation by tallying the Seyfert content in the RSA (Bγ < 13.4 mag) based on spectral classifications taken from the literature. They deduced a lower limit of 5% for the frequency of Seyfert nuclei in nearby galaxies, but, based on completeness considerations, they argued that the true frequency could be as high as 16%. Their lower limit, while consistent with our results, is too low by a factor of ∼2, and their estimate of the true frequency appears to be somewhat high. Since Maiolino & Rieke based their study on published material, it is not surprising that they too missed many of the Seyferts recovered in our survey. Indeed, a significant fraction of the published classifications they used were drawn from the very studies that we evaluated relative to the Palomar survey in § 1. Only half of the 52 Seyferts in the Palomar sample appear in the tabulation of Maiolino & Rieke (1995).

9. CONCLUDING SUMMARY

A large sample of emission-line nuclei has been identified 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. Table 1 gives a synopsis of their main characteristics, and Table 2 summarizes the detection rates of the different object classes. This paper reports the detection rate of line emission in the central regions of galaxies, the incidence of different classes of emission-line nuclei, and their dependence on the morphological type and luminosity of the host galaxy type. The main conclusions of this paper, based on 420 emission-line nuclei selected from a magnitude-limited (Bγ ≤ 12.5 mag) sample of 486 northern (δ > 0°) galaxies, are as follows:

1. As is consistent with previous studies, the central few hundred parsecs of most galaxies (86%) have detectable amounts of ionized gas, as traced by optical emission lines. The detection rate essentially reaches 100% for spiral galaxies.

2. The emission-line nuclei divide nearly equally in number between H II nuclei and AGNs, where AGNs collectively refer to Seyfert nuclei, LINERs, and transition objects (composite LINER/H II nuclei). The AGN fraction in nearby galaxies is therefore very high, on the order of 43%. Unfortunately, the incidence of galaxies harboring a central massive black hole is still quite uncertain. The AGN fraction could be considerably lower if, for instance, it turns out that many transition objects do not contain LINER nuclei, or if only a minority of LINERs are genuine AGNs. We argue in Paper VI that this is unlikely to be the case. On the other hand, very weak AGNs can be hidden by brighter nuclear H II regions, or they may contain undetectably small amounts of ionized gas, and so at least some faint objects must undoubtedly have escaped notice. Efforts to quantify these effects are in progress.

3. 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).

4. LINERs are found in one-fifth to one-third of all galaxies and, under the assumption that they are genuine AGNs, they constitute between one-half and three-quarters of the AGN population, depending on whether transition objects are excluded or included in the LINER group.

5. Broad-lined or "type 1" AGNs make up ∼20% of the AGN population and ∼10% of all galaxies. Approximately half of type 1 objects belong to the LINER category.

6. The dominant excitation mechanism of nuclear emission depends strongly on the Hubble type and integrated luminosity of the host galaxy. AGNs reside mainly in early-type (E–Sbc) galaxies and H II nuclei in late-type (Sbc and later) systems. AGN hosts are more luminous than non-AGN hosts, because early-type galaxies tend to be more luminous than late-type galaxies.

7. The subclasses of AGNs have broadly similar distributions of host galaxy morphological types and luminosities. The only noticeable difference is that a higher proportion of
pure LINERs is found in elliptical galaxies, while a higher fraction of transition objects tend to be found in late-type hosts.

8. The typical object has quite modest emission-line strengths, with Hα equivalent widths of only a few angstroms and luminosities (after correcting for extinction) of $\sim 10^{39}$ ergs s$^{-1}$.

9. The detection rates of the various classes of emission-line objects are unlikely to be seriously incomplete or affected by selection biases due to distance or inclination.

We thank the referee, Tim Heckman, for helpful comments on the manuscript. The research of L. C. H. is currently funded by a postdoctoral fellowship from the Harvard-Smithsonian Center for Astrophysics. Financial support for this work was provided by NSF grants AST 89-57063 and AST 92-21365, by NASA grant NAG 5-3556, and by NASA grants AR-5291-93A and AR-5792-94A from the Space Telescope Science Institute (operated by AURA, Inc., under NASA contract NAS 5-26555).

REFERENCES

Adams, T. F. 1977, ApJS, 33, 19
Balzano, V. A. 1983, ApJ, 268, 602
Burbidge, E. M., & Burbidge, G. 1962, ApJ, 135, 694
Ciardullo, R., Rubin, V. C., Jacoby, G. H., Ford, H. C., & Ford, W. K., Jr. 1988, AJ, 95, 438
Dahari, O., & De Robertis, M. M. 1988, ApJS, 67, 249
de Vaucouleurs, G. 1959, Hand. Phys., 53, 275
———. 1963, ApJS, 8, 31
Filippenko, A. V. 1996, in ASP Conf. Ser. 103, The Physics of LINERs in View of Recent Observations, ed. M. Eracleous et al. (San Francisco: ASP), 17
Filippenko, A. V., & Sargent, W. L. W. 1985, ApJS, 57, 503 (Paper I)
Heckman, T. M. 1980a, A&A, 87, 142
———. 1980b, A&A, 87, 152
———. 1996, in ASP Conf. Ser. 103, The Physics of LINERs in View of Recent Observations, ed. M. Eracleous et al. (San Francisco: ASP), 214
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1993, ApJ, 417, 63
———. 1995, ApJS, 98, 477 (Paper II)
———. 1997a, ApJS, in press (Paper III)
———. 1997b, in preparation (Paper VI)
———. 1997d, ApJ, 487, 591
Ho, L. C., Filippenko, A. V., Sargent, W. L. W., & Peng, C. Y. 1997c, ApJS, in press (Paper IV)
Huchra, J. P., & Burg, R. 1992, ApJ, 393, 90

Keel, W. C. 1983a, ApJS, 52, 229
———. 1983b, ApJ, 269, 466
Khachikian, E. Y., & Weedman, D. W. 1974, ApJ, 192, 581
Kirshner, R. P., Oemler, A., Jr., & Schechter, P. L. 1979, AJ, 84, 951
Maiolino, R., & Rieke, G. H. 1993, ApJ, 454, 95
Phillips, M. M., Charles, P. A., & Baldwin, J. A. 1983, ApJ, 266, 485
Phillips, M. M., Jenkins, C. R., Dopita, M. A., Sadler, E. M., & Binette, L. 1986, AJ, 91, 1062
Pogge, R. W. 1989, ApJS, 71, 433
Press, W. H., Flannery, B. P., Teukolsky, S. A., & Vetterling, W. T. 1986, Numerical Recipes: The Art of Scientific Computing (Cambridge: Cambridge Univ. Press)
Roberts, M. S., & Haynes, M. P. 1994, ARA&A, 32, 115
Rubin, V. C., & Ford, W. K., Jr. 1971, ApJ, 170, 25
———. 1980, ApJ, 269, L35
Sandage, A. R., & Tammann, G. A. 1981, A Revised Shapley-Ames Catalog of Bright Galaxies (Washington, DC: Carnegie Inst. Washington) (RSA)
Sandage, A. R., Tammann, G. A., & Yahil, A. 1979, ApJ, 232, 352
Stauffer, J. R. 1982a, ApJS, 50, 517
———. 1982b, ApJ, 262, 66
Terlevich, R., Mcllitch, J., & Mokesh, M. 1987, in Observational Evidence of Activity in Galaxies, ed. E. Ye. Khachikian, K. J. Fricke, & J. Mclnwick (Dordrecht: Reidel), 499
Veilleux, S., & Osterbrock, D. E. 1987, ApJS, 63, 295
Véron, P., & Véron-Cetty, M.-P. 1986, A&A, 161, 145
Véron-Cetty, M.-P., & Véron, P. 1986, A&A, 66, 335
Weedman, D. W. 1977, ARA&A, 15, 69