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LOW-LUMINOSITY AND OBSCURED SEYFERT NUCLEI IN NEARBY GALAXIES

R. MAIOLINO[1,2] AND G. H. RIEKE[3]
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ABSTRACT

We discuss the Seyfert galaxies in the Revised Shapley-Ames catalog ($B_T < 13.31$) and in three extensions to it ($B_T < 13.4$). The sample contains 91 relatively nearby Seyfert galaxies. The proximity of the objects reduces the dilution of their nuclear spectra by the host galaxy light. As a consequence, biases against low-luminosity nuclei (relative to the host) and against edge-on galaxies are reduced compared with other samples of Seyfert galaxies.

From this sample, we set a lower limit of 5% to the portion of galaxies with Seyfert nuclei; completeness arguments could support a percentage as high as 16%. We find type 2 Seyfert nuclei (i.e., types 1.8 + 1.9 + 2) to be 4 times more numerous than type 1 ones (types 1 + 1.2 + 1.5). Seyfert nuclei of types 1 + 1.2 + 1.5 are mostly found in face-on galaxies, while intermediate nuclei of types 1.8 + 1.9 are mostly found in edge-on hosts. These results suggest that most of the intermediate type Seyfert nuclei are type 1 nuclei seen through a 100 pc–scale torus coplanar with the galactic disk and *not* type 1 nuclei partially obscured by an inner parsec-scale torus.

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

1. INTRODUCTION

Several theories dealing with Seyfert galaxies must be tested through a statistical approach; they are thus critically dependent on the selection criteria of the sample. For various reasons, no available sample of Seyfert galaxies is free of biases, making it critical to understand a variety of samples to allow correction for the relevant shortcomings of each. For example, Seyfert samples selected on the basis of UV or X-ray excess are known to favor type 1 nuclei. Moreover, UV excess and X-ray emission are quantities strongly related to the Seyfert activity and are thus likely to bias the sample toward high-luminosity active nuclei. Samples selected according to their IR properties (e.g., the 12 μm sample; Rush, Malkan, & Spinoglio 1993) are likely to be biased toward galaxies experiencing high star formation activity as well as toward bright Seyfert nuclei.

The CfA Seyfert sample (Huchra & Burg 1992, hereafter HB92) is considered to be one of the least biased samples: it is drawn from the magnitude-limited ($m_{Zw} < 14.5$) CfA redshift sample and spectroscopically selected. However, because the CfA sample contains many galaxies at relatively high redshifts, it might miss faint Seyfert nuclei in bright systems, as HB92 warn. Such a selection effect is clear in HB92's Figure 1, where the nuclear magnitudes are plotted versus the integrated magnitudes: it shows the decreasing ability to detect faint nuclei as the host galaxy luminosity increases. The sample also appears to exclude edge-on galaxies (McLeod & Rieke 1995).

In this paper, we assess the influence of these two remaining biases on our current ideas about Seyfert galaxies. We show that the two effects are greatly reduced in a sample of the nearest Seyfert galaxies. As a result, we can use these galaxies to examine the placement of obscuring material around the nucleus that causes edge-on galaxies to drop below the threshold for inclusion in other Seyfert samples. We can also place limits on the influence of low-luminosity nuclei on our estimates of the relative proportions of Seyfert types and on the portion of galaxies with Seyfert nuclei.

2. PROPERTIES OF THE SAMPLE

We have defined a sample containing all galaxies with $B_T <$ 13.4 that are found to host a Seyfert nucleus from data in the literature. Details of the rigorous membership criteria and a listing of the members are contained in the Appendix. There are four nested subsamples: sample A contains 62 Seyfert galaxies in the Revised Shapley-Ames catalog (RSA; Sandage & Tammann 1987, hereafter ST87); sample B adds 13 galaxies from the extension to the RSA (ST87); sample C adds 11 more galaxies from the literature, primarily accounting for the southern hemisphere counterparts to the Seyfert galaxies in the RSA extension; and sample D adds five more galaxies that have $B_T < 13.4$ when corrected for Galactic extinction.

2.1. *Distance Distribution*

The average distance[4] of the galaxies in sample A is $\langle d_A \rangle =$ 27 Mpc. Going toward sample D, the average distance does not increase much: $\langle d_D \rangle = 34$ Mpc. Thus, these galaxies are closer than the other samples of Seyfert galaxies. For instance, the average redshift for the CfA Seyfert sample is about 3 times greater than for our samples, while the 12 μm sample Seyfert galaxies are on average even more distant (140 Mpc). The relative nearness of our samples makes the nuclear spectra less diluted by the host galaxy light, making it easier to detect faint Seyfert nuclei, especially when they lie in bright galaxies. As a consequence, several biases that affect other samples are reduced, as we discuss below.

2.2. *Inclusion of Low-Luminosity AGNs*

Seyfert galaxies selected by criteria such as ultraviolet or infrared excess are very likely to be biased toward high-

[1] Dipartimento di Astronomia e Scienza dello Spazio, Università di Firenze, Largo E. Fermi 5, 50125 Firenze, Italy.

[2] Currently at Steward Observatory.

[3] Steward Observatory, University of Arizona, Tucson, AZ 85721.

[4] Distances are calculated by correcting the redshifts for a Virgocentric infall of 300 km s^{-1} and assuming a Hubble constant of 75 km s^{-1} Mpc^{-1}. Distances of objects belonging either to the Virgo and Fornax Cluster or to the NGC 5128 group have been calculated as specified by ST87.

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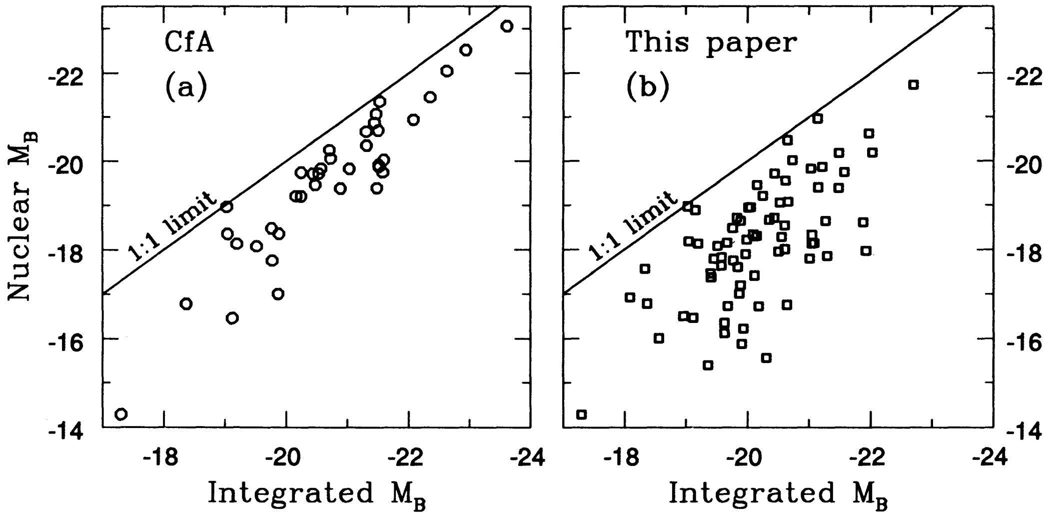

FIG. 1.—Integrated vs. nuclear ($\sim 16''$ beam size) absolute blue magnitude, for (*a*) the CfA sample and (*b*) our sample D

luminosity active galactic nuclei (AGNs). Even for the CfA sample, the nuclear luminosity is closely linked to the galaxy integrated luminosity. In Figure 1*a* we plot, as HB92 do, the integrated absolute magnitude versus the "nuclear" magnitude, obtained by small-beam (typically $\sim 16''$) photometry[5] of the CfA Seyfert galaxies. We note the absence of nuclei which are weak with respect to the galaxy luminosity; the distribution is instead closely aligned with the 1:1 limit. Such a selection effect might have significant consequences for the observed numbers of type 2 Seyfert nuclei in particular, since these nuclei are underluminous in the optical with respect to type 1 Seyfert nuclei. The 16" beam might include a significant contribution from the galaxy stellar light which might affect the diagram in Figure 1. Thus, we checked further for such a bias effect in the CfA by looking at the distribution of the [O III] λ5007 emission line strength,[6] which is a more direct indicator of nuclear activity. In Figure 2*a* we show the distribution of the [O III] line luminosity versus the total absolute blue magnitude; a selection effect is apparent against Seyfert nuclei with low activity levels (i.e., low [O III] emission) in bright host galaxies.

The selection effect is greatly reduced in our sample. In Figure 1*b* we plot the nuclear versus integrated M_B for the objects in our sample D having available nuclear data; in Figure 2*b* we plot the [O III] luminosity versus the integrated M_B for the same sample. It is noticeable that many of these objects have Seyfert nuclei which are weak with respect to the host galaxy.

Various authors have claimed a correlation between the Seyfert nuclear activity and the luminosity of the host galaxy. Such a correlation probably just reflects the bias against low-luminosity nuclei with respect to the host galaxy. A detailed

[5] The small beam photometry data for the CfA, as well as for our sample, are taken from Cruz-Gonzalez (1985), Longo & de Vaucouleurs (1983, 1985), Winkler (1992), Hamuy & Maza (1987), and other references listed in Véron-Cetty & Véron (1993).

[6] The [O III] λ5007 line fluxes are taken from Dahari & DeRobertis (1988), references in Whittle (1992), and references listed in Table 2

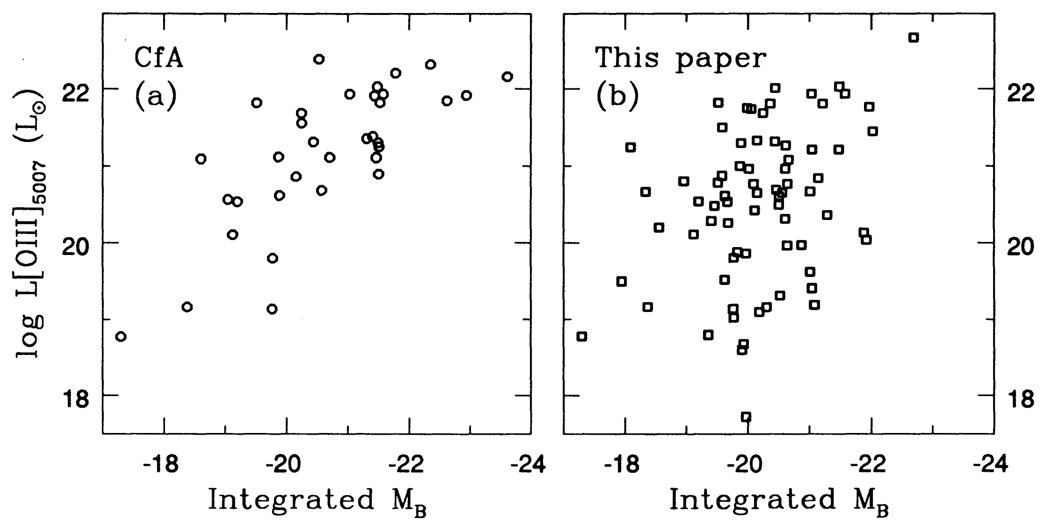

FIG. 2.—Integrated absolute blue magnitude vs. [O III] λ5007 emission-line luminosity, for (*a*) the CfA sample and (*b*) our sample D. Note that the CfA misses low activity Seyfert nuclei as the luminosity of the host galaxy increases. Such selection effects are much reduced in our sample.

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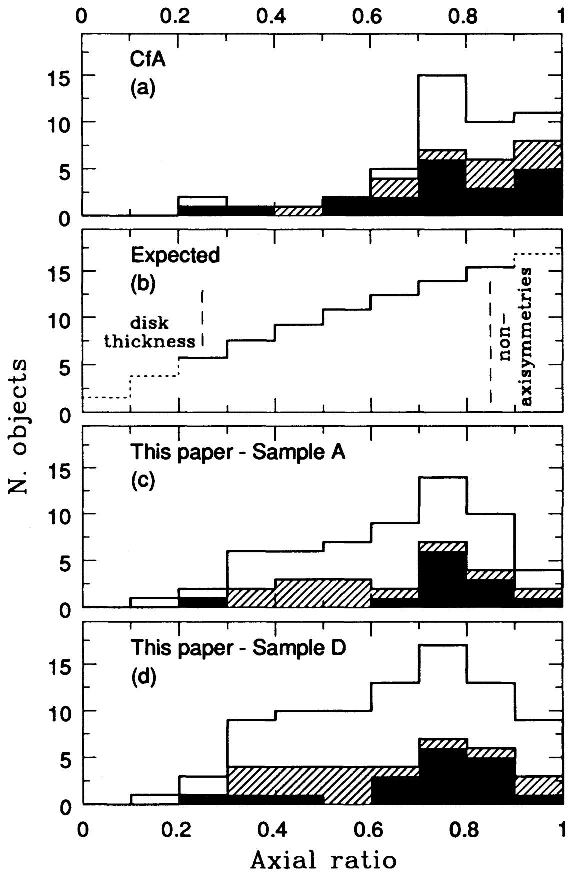

FIG. 3.—Axial ratio distribution (*a*) for the CfA sample, (*b*) expected for a magnitude-limited sample of thin circular disks, (*c*) for our sample A, and (*d*) for our sample D. Filled bars are for types 1 + 1.2 + 1.5, shaded bars are for types 1.8 + 1.9, and empty bars are for type 2. The histogram is cumulative; i.e., in each bin the number of objects for each group of Seyfert types is given by the difference of the height of the bars. Note the bias in the CfA against edge-on host galaxies. Such bias is much reduced in our samples.

discussion of this effect can be found in McLeod & Rieke (1995).

2.3. *Galaxy Axial Ratio*

Seyfert nuclei mostly lie in spiral galaxies. As discussed by McLeod & Rieke (1995) and references given by them, most of the Seyfert samples are biased against edge-on galaxies: very few Seyfert nuclei are found in galaxies with axial ratios below 0.7. We show the axial ratio distribution for the CfA case in Figure 3*a* (we exclude elliptical and peculiar galaxies and ones too far away to allow an evaluation of the axial ratio).[7] Filled bars are for type 1 + 1.2 + 1.5 Seyfert galaxies, shaded bars are for type 1.8 + 1.9 Seyfert galaxies, and empty bars are for type 2 Seyfert galaxies. The histogram bars are cumulative (i.e., the relative numbers of the three Seyfert groups are given by the height differences).

In a magnitude-limited sample, edge-on systems are expected to be less numerous because internal absorption shifts them above the limiting magnitude. This effect leads to the following distribution for the axial ratios:

$$dN(r) \propto r^{3\beta/5}\, dr \,, \quad (1)$$

where r is the axial ratio, $dN(r)$ is the number of objects with axial ratio between r and $r + dr$, and $\beta = 1.34$ for Sa–Sb galaxies (ST87). Equation (1) does not account for the effect of the disk thickness and possible nonaxisymmetric morphologies; thus, the formula is not trustworthy for low and high axial ratios. The distribution given by equation (1) is shown in Figure 3*b* (with an arbitrary normalization), and it is inconsistent with the CfA Seyfert distribution.

In Figures 3*c* and 3*d*, we report the axial ratio distribution both for the A and the D samples, with the same formalism and rejection criteria as in Figure 3*a*. The lack of edge-on galaxies is much reduced. The Seyfert nuclei in edge-on galaxies tend to have lines weaker than their face-on counterparts; edge-on Seyfert galaxies are retained by our sample because of the greater detectability of faint Seyfert nuclei in nearby galaxies. The lack of objects below $r = 0.2$–0.3 is expected because of the disk thickness. Noncircular disks might be responsible for the drop above $r = 0.8$ (see discussion in Binney & de Vaucouleurs 1981); in addition, the bias of the RSA against low surface brightness systems might play a role.

Defining "broad-line Seyfert" to include types 1 + 1.2 + 1.5 + 1.8 + 1.9, it is interesting to note that the fraction of type 2 Seyfert galaxies to broad-line Seyfert galaxies is roughly independent of the inclination of the galaxy disk. However, within the broad-line Seyfert galaxies, a progression is apparent in the portion of intermediate types with the inclination of the galaxy disk: types 1 + 1.2 + 1.5 mostly appear in face-on hosts, while intermediate types 1.8 + 1.9 are mostly found in edge-on galaxies. We checked the statistical significance of this trend by applying the Kolmogorov-Smirnov (K-S) test (Mises 1964) to the axial ratio distributions. The results of such tests are given in Table 1, in which we report the probability for the two compared distributions to be drawn from different parent distributions. We find that the axial ratio distributions of *intermediate* Seyfert galaxies (1.8 + 1.9) and of type 1 Seyfert galaxies (1 + 1.2 + 1.5) are different at high confidence levels; that is, *intermediate* Seyfert galaxies are likely to be found in edge-on galaxies, while type 1 Seyfert galaxies are likely to be found in face-on galaxies. On the other hand, we find that the axial ratio distribution of *strict* type 2 Seyfert galaxies is unlikely to be different from that of *broad-line* Seyfert galaxies. The small number of intermediate-type Seyfert galaxies in nearly face-on galaxies may originate from extinction in or near the parsec-scale circumnuclear torus. However, our results suggest that

TABLE 1

K-S TEST FOR THE AXIAL RATIO DISTRIBUTIONS IN FIGURES 3*b*–3*c*

SEYFERT DISTRIBUTIONS	SAMPLE A	SAMPLE D
Intermediate Seyfert vs. Seyfert 1 + 1.2 + 1.5	99.0%	97.3%
Seyfert 2 vs. Broad-line Seyfert	10.1	1.0

NOTES.—First row: probability for the *intermediate* Seyfert (Seyfert 1.8 + 1.9) and Seyfert 1 + 1.2 + 1.5 axial ratio distributions to be drawn from two different distributions. Second row: the same probability when comparing the axial ratio distributions of *strict* Seyfert 2 and *broad-line* Seyfert galaxies (Seyfert 1 + 1.2 + 1.5 + 1.8 + 1.9). In the first case, the two distributions are very likely to be different; the opposite can be said in the second case.

[7] The axial ratios are taken either from RC3 (de Vaucouleurs et al. 1991) or from McLeod & Rieke (1995).

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most of the intermediate Seyfert galaxies are the counterparts of type 1 Seyfert galaxies, but seen in more nearly edge-on galaxies where they are subject to additional extinction associated with the larger scale (~ 100 pc) obscuring material around the nucleus and in the plane of the galaxy.

2.4. *Completeness Considerations*

Completeness corrections for the RSA sample are discussed by Sandage, Tammann, & Yahil (1979). If the distribution of our sample were the same as the parent sample, we could apply these corrections. However, as shown in Figure 4, the distribution of the apparent magnitude B_T for all galaxies in the RSA differs significantly from the same distribution for the Seyfert galaxies in the RSA (our sample A): the Seyfert sample has a larger portion of bright galaxies. Such an effect cannot be entirely caused by poor statistics; indeed, the Kolmogorov-Smirnov test applied to the two distributions in Figure 4 gives a probability of 97% for them to be drawn from different distributions. The effect is probably the result of less complete identification of Seyfert nuclei in the fainter (and hence more distant and less thoroughly studied) members of the parent sample.

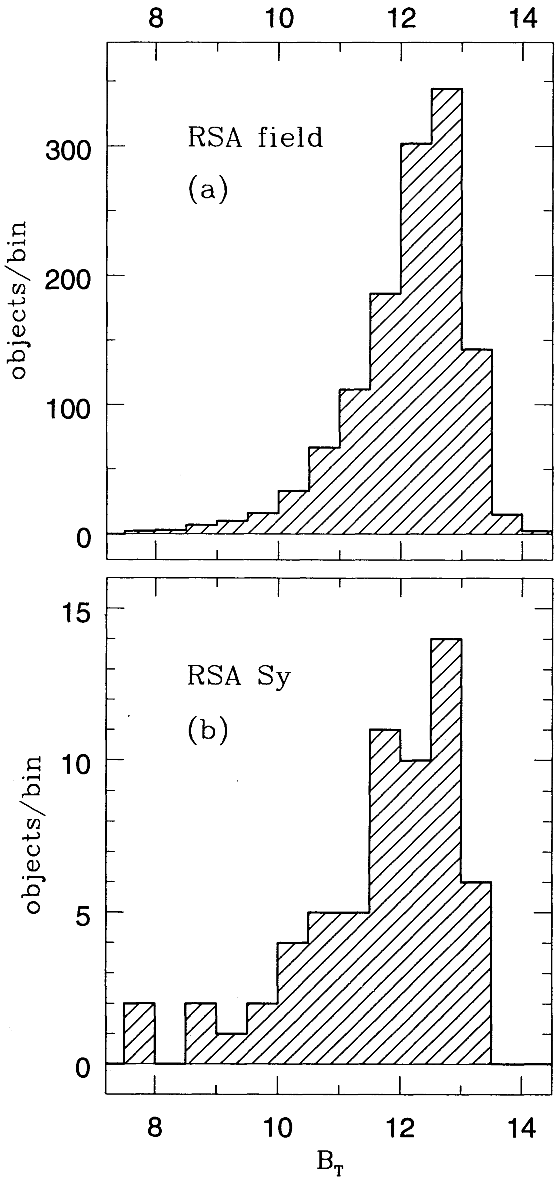

FIG. 4.—Apparent magnitude distribution for (*a*) the whole RSA sample and (*b*) the Seyfert galaxies in the RSA, i.e., sample A.

2.5. *Portion of Seyfert Galaxies among All Galaxies*

The portion of Seyfert galaxies in the RSA sample has been discussed by Véron-Cetty & Véron (1986a) and Woltjer (1990), who have found a larger fraction than in other samples. Hereafter, we address this issue by means of our larger and rigorously selected sample.

For a complete sample, the portion of Seyfert galaxies should be estimated by means of the luminosity function. However, this method is correct only if the sample is complete with respect to its parent sample. All the Seyfert samples (including ours) seem to be incomplete. Therefore, we can only estimate a lower limit to the portion of Seyfert galaxies by comparing the number of objects in our sample A with that in the whole RSA. We find a lower limit of 5% for the occurrence of the Seyfert phenomenon among galaxies.

In principle, we could estimate the real fraction of Seyfert galaxies from the bright tails of the distributions in Figure 4. Below 10–11 mag, the incompleteness of Seyfert galaxy identifications appears to be reduced; nonetheless, few objects are present in this bright tail, thus making the statistics quite poor. There are 12 objects in sample A with $B_T < 10.5$ mag; when compared with the number of objects in the RSA in the same magnitude range, we find a fraction of 16% (± 5%) with Seyfert nuclei.

2.6. *The Seyfert 2 to Seyfert 1 ratio*

The recovery of many faint Seyfert 2 nuclei has consequences for the Seyfert 2 to Seyfert 1 ratio:[8] our sample recovers many Seyfert 2 nuclei in edge-on systems that are absent in Seyfert samples such as the CfA. Since in our sample the different Seyfert types do not have significantly different distributions of B_T, i.e., no differential selection effect, we can estimate the Seyfert 2 to Seyfert 1 ratio from the raw source counts. By grouping types 1.8 + 1.9 + 2 in type 2 and 1 + 1.2 + 1.5 in type 1,[9] we obtain a Seyfert 2 to Seyfert 1 ratio of 4:1. This ratio does not change from sample A to sample D. Other authors use the luminosity function to estimate the Seyfert 2 to Seyfert 1 ratio, but we believe that such luminosity functions are not reliable owing to incompleteness.

The relative number of Seyfert 2 to Seyfert 1 galaxies that we have found is higher than in the CfA sample ($\sim 1:1$) and in the 12 μm sample ($\sim 1:1$, though slightly different grouping criteria are adopted in the latter). Better agreement is found with the Wasilewsky (1983) sample, where Osterbrock & Shaw (1988) find the relative number of Seyfert 2 to Seyfert 1 galaxies to be about 3:1.

If the unified model is assumed, than the Seyfert 2 to Seyfert 1 ratio gives the average opening angle of the light cones. A 4:1 ratio corresponds to a 74° opening angle. The latter is in reasonably good agreement with most of the available obser-

[8] NGC 1097 is not used for the discussion in this section because its type has changed over time.

[9] Different authors use different groupings. For instance, HB92 tend to group in the same way we do, but Rush et al. (1993) tend to group types 1 + 1.5 + 1.8 + 1.9 together in type 1.

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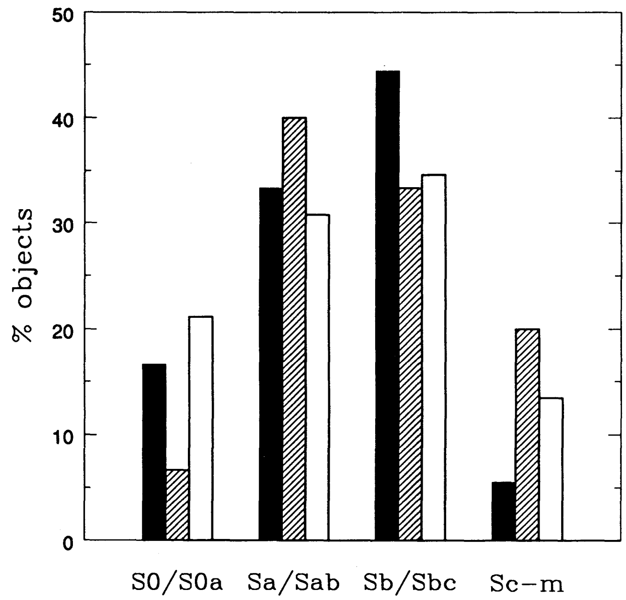

FIG. 5.—Distribution of the Hubble type for the hosts of Seyfert nuclei in our sample D. Filled bars are for Seyfert 1 + 1.2 + 1.5, shaded bars are for Seyfert 1.8 + 1.9, and empty bars are for Seyfert 2. The percentages are with respect to the total number of objects within each group of Seyfert types.

vational results on light cones in individual galaxies: 75° in NGC 5252 (Tadhunter & Tsvetanov 1989), 65° and 80° in NGC 1068 (Evans et al. 1991 and Bergeron, Petitjean, & Durret 1989, respectively), 74° in Mrk 3 and 60° for Mrk 573 (Pogge & De Robertis 1993), 75° in Circinus (Marconi et al. 1994), 55°–65° in NGC 5728 (Wilson et al. 1993), and 50°–92° in NGC 4388 (Pogge 1989).[10]

If Seyfert 2 galaxies are further split into strict Seyfert 2 and intermediate Seyfert 1.8 and Seyfert 1.9, we also obtain a relative proportion of *strict* Seyfert 2: *intermediate* Seyfert (1.8 + 1.9): Seyfert 1 (1 + 1.2 + 1.5) equal to 3:1:1. However, as discussed in the Appendix the distinction between Seyfert 1.8 + 1.9 galaxies and true Seyfert 2 galaxies may not be totally reliable owing to shortcomings in the available spectra.

2.7. *Host Galaxy Types*

Figure 5 shows the distribution of the Hubble types, as given in NED,[11] for the host galaxies of different Seyfert types. Filled bars are for Seyfert 1 + 1.2 + 1.5, shaded bars are for Seyfert 1.9 + 1.8, and open bars are for strict Seyfert 2. The percentages are calculated with respect to the total number of objects in each group. The distribution confirms previous claims that the Seyfert phenomenon occurs mostly in early Sa–Sb spiral hosts. No significant difference is found in the Hubble class distribution for hosts of different Seyfert nuclear types. A similar result also holds for the CfA sample (McLeod & Rieke 1995).

2.8. *Possible Biases*

We now consider how incompleteness or other biases might affect the conclusions in the preceding sections.

In § 2.4, we found a trend for increasing incompleteness in this sample as the host galaxies become fainter. From § 2.5, we cannot tell whether this incompleteness is modest or whether it is as large as a factor of 3. It seems likely that the missing Seyfert nuclei in relatively faint hosts are predominantly low-luminosity AGNs, since the more luminous examples would have become apparent in all-sky surveys, for example in the X-ray or infrared, and hence they would have been found in our literature survey. In fact, as X-ray surveys improve in sensitivity, an increasing number of nearby galactic nuclei with hard, AGN-like spectra are being detected (e.g., Makishima et al. 1994). Therefore, although our sample includes many more low-luminosity nuclei than do samples selected by other means, the bias toward underestimation of the number of these objects is only partially removed. The relatively heavy obscuration of Seyfert 2 nuclei in the soft X-ray, UV, optical, and near and mid-infrared suggests that the majority of the missing galaxies will have Seyfert 2 nuclei. Hence, although we already find the portion of Seyfert 2 nuclei to be higher than in most previous studies, the number of these nuclei probably remains understated.

We can identify no reason why this incompleteness should affect the relative proportions of Seyfert types as a function of galaxy orientation. However, the distribution of apparent orientations might be influenced by any systematic correlation between host galaxy morphological type and the type of the Seyfert activity. For example, if type 1 Seyfert nuclei occurred predominantly in elliptical and S0 galaxies and type 2 Seyfert nuclei occurred in late-type spirals, then the systematically differing galaxy shapes could help account for the tendency to find only type 1.8–2 nuclei in galaxies with large axial ratios. However, in our sample we find that there is no significant difference in the distribution of host galaxy types as a function of the type of Seyfert activity. In this regard, our sample is similar to what is found for the CfA sample (McLeod & Rieke 1995). In addition, any such trend would be unable to explain why the distribution of axial ratios was so different between the CfA sample and ours, unless the distribution of host galaxy types was different between the two samples, which it is not.

Improved spectra, or spectra in the near-infrared, always have the potential to show faint broad wings on the lines of a galaxy currently classified as Seyfert 2, leading to its reclassification as Seyfert 1.8 or 1.9. However, it can be seen from Figure 3 that the changes in distribution of types with axial ratio would be modest.

Finally, the degree of incompleteness, the proportion of type 2 Seyfert galaxies, and the number of low-luminosity Seyfert galaxies are all dependent on the division made between Seyfert and low-ionization nuclear emission-line region (LINER) activity. Although we have tried to be rigorous in our definition of Seyfert activity, there will always be ambiguous cases, as discussed in the Appendix. In addition, it is not yet clear whether the LINER definition always indicates galaxies where the physical processes in the nuclei are distinct from those in Seyfert nuclei, or whether a physically based classification would group some cases currently termed LINERs with the Seyfert galaxies. However, we note that there are only six ambiguous cases in our total sample of 91 galaxies (see Appendix), so the arbitrariness of the division between Seyfert and LINER is unlikely to have a large effect on our conclusions.

3. GEOMETRY OF THE CIRCUMNUCLEAR MATERIAL

In most samples defined either optically or in the ultraviolet (and perhaps also in soft X-rays), both type 1 and type 2 Seyfert

[10] We do not quote Pogge's result for NGC 2110 because the ionized gas distribution in this object is still a matter of debate (e.g., Haniff, Ward, & Wilson 1991; Mulchaey, Wilson, & Bower 1994).

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nuclei tend to appear only in face-on host galaxies, as summarized by McLeod & Rieke (1995). They argue that there must be a circumnuclear torus of obscuring material on a roughly 100 pc scale and coplanar with the galaxy, so that it can be effective in obscuring the narrow-line region (NLR) and hence in hiding Seyfert 2 nuclei.

Because of its orientation and the level of extinction associated with it, the "outer torus" is probably not a coherent structure, but it represents clouds of molecular material migrating from the galaxy disk into the nucleus. We now speculate on the mechanism that disrupts these clouds when they approach within a few tens of parsecs of the nucleus, so that an adequate aperture ($\sim 60°$ half-angle; McLeod & Rieke 1995) is opened to make the nucleus visible in face-on galaxies. We assume that the AGN is powered by a central black hole of mass 10^8–10^9 $M_\odot$.

If the gravitational potential is dominated by a nuclear mass, then the Roche limit requires that molecular clouds be tidally destroyed when they approach within a distance (Lang 1980, p. 280)

$$R(\mathrm{pc}) = 2.5[M_{\mathrm{BH}}(M_\odot)/\rho(\mathrm{cm}^{-3})]^{1/3} . \quad (2)$$

Thus, a molecular cloud of density 10^4 cm^{-3} orbiting a black hole of 10^8 $M_\odot$ would be destroyed when it approached within 55 pc. So long as the mass is dominated by an extended distribution (e.g., stars), these tidal forces will be softened. However, since a typical large spiral galaxy has a mass of 10^8–10^9 $M_\odot$ in stars within its central 100 pc radius, as a typical molecular cloud in a Seyfert galaxy penetrates within this radius, it will eventually encounter a gravitational potential dominated by the nuclear black hole, and hence the cloud will be disrupted. Once disruption has occurred, the self-shielding of the cloud is removed, and we speculate that the ambient ultraviolet radiation field around the AGN ionizes the resulting diffuse distribution of interstellar gas, possibly contributing to (or constituting) the NLR of the galaxy.

There is a variety of observational evidence in favor of this interpretation. First, there are a number of cases where molecular line observations suggest the presence of complexes of molecular clouds in a ringlike structure about 100 pc from the nuclei of spiral galaxies (e.g., Gusten 1989, and references therein for the Milky Way; Sofue 1991 and Bergman et al. 1992 for external galaxies). Tacconi et al. (1994) find evidence for such a structure in the type 2 Seyfert galaxy NGC 1068. On a much smaller scale, we see exactly the structure envisioned for the Seyfert nuclei in the Galactic center. There is a ring of molecular clouds orbiting the nucleus. Inside the ring there is a cavity with a radius of about 1 pc, threaded with streamers of ionized gas. The smaller scale of the transition to tidally disrupted clouds is as expected because of the much smaller black hole mass ($\sim 10^6$ $M_\odot$).

Since our sample recovers many Seyfert nuclei in edge-on galaxies, it can be used to study this large-scale effect. As discussed in § 2.3, our results suggest that intermediate Seyfert nuclei (1.8 + 1.9) are the counterparts of Seyfert type 1 nuclei (1 + 1.2 + 1.5) in edge-on galaxies. Therefore, it is possible that the intermediate nuclei are type 1 objects seen through the 100 pc scale torus and are not type 1 objects partially obscured by the parsec-scale circumnuclear torus. This proposed geometry is depicted in Figure 6. The inner, small torus is responsible for the complete obscuration of the broad-line region (BLR) along certain lines of sight, making the spectrum type 2; this inner

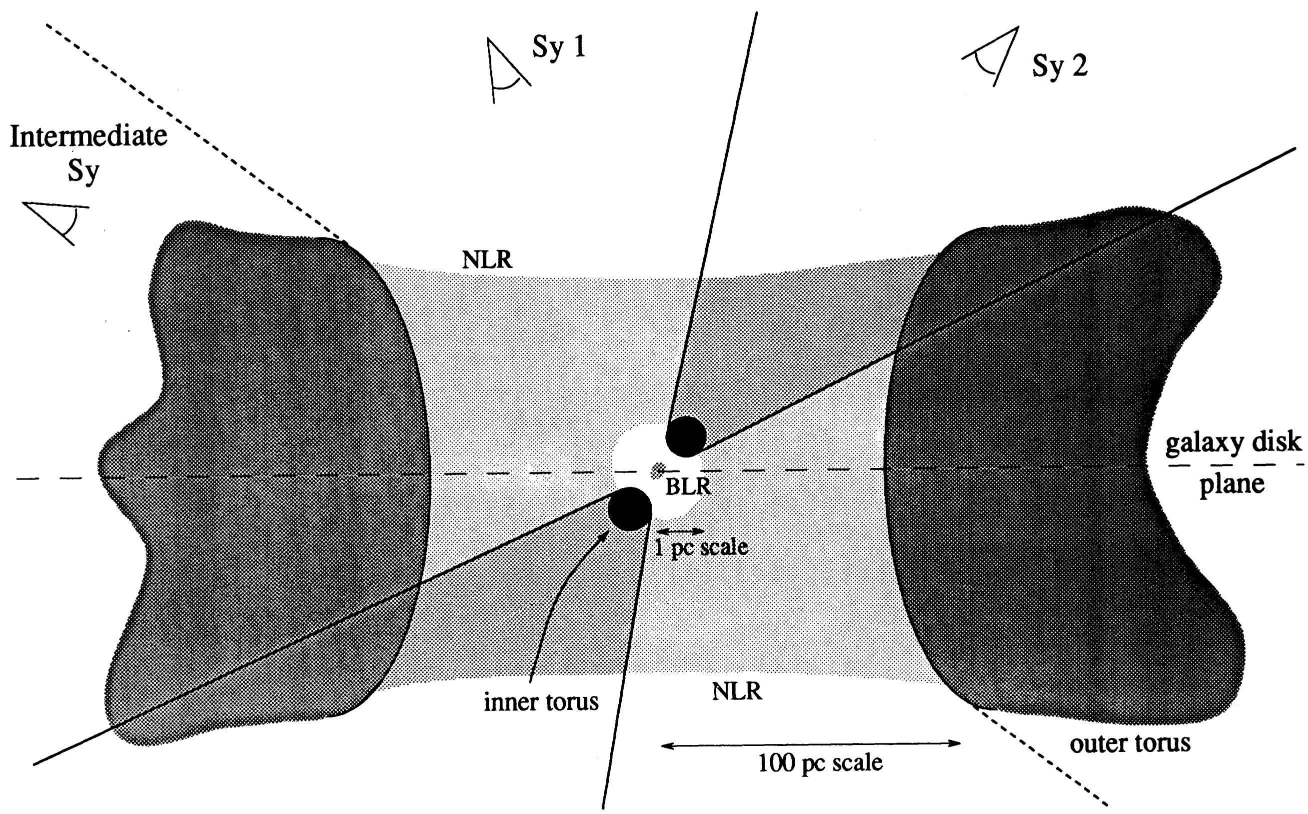

FIG. 6.—Proposed geometry of Seyfert nuclei depicted by a cross section of the nucleus perpendicular to the galactic plane

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torus is oriented randomly relative to the plane of the galaxy, as indicated by the similarity of the axial ratio distribution between strict Seyfert 2 and broad-line Seyfert galaxies (Table 1). The hot dust seen in the near- and mid-infrared also lies in or near this torus. The outer torus partially obscures both the NLR and the BLR, reducing the visibility of the Seyfert spectrum in all edge-on systems and, where the inner torus is suitably oriented, shifting type 1 spectra toward intermediate types (since the BLR is more effectively obscured than the more extended NLR).

If the model depicted in Figure 6 is true, we would expect narrow lines, such as the [O III] λ5007, to be generally weaker in type 1.8 + 1.9 Seyfert galaxies than in type 1–1.5, when allowance is made for intrinsic differences in nuclear activity. Figure 7*a* shows the distribution of the [O III] luminosity for intermediate Seyfert galaxies (*shaded bars*) and Seyfert 1–1.5 (*filled bars*). The latter have [O III] lines which are systematically more luminous than intermediate Seyfert galaxies. The K-S test gives a 99.9% confidence level for the two distributions to be different. The same model would predict no differences in the [O III] luminosity distribution between Seyfert 2 and broad-line Seyfert galaxies (Seyfert 1 + 1.2 + 1.5 + 1.8 + 1.9). Figure 7*b* shows the distribution of the [O III] luminosity for Seyfert 2 (*empty bars*) and broad-line Seyfert galaxies (*shaded bars*); the two distributions are indeed quite similar, the K-S test giving only a small probability (34%) for them to be different.

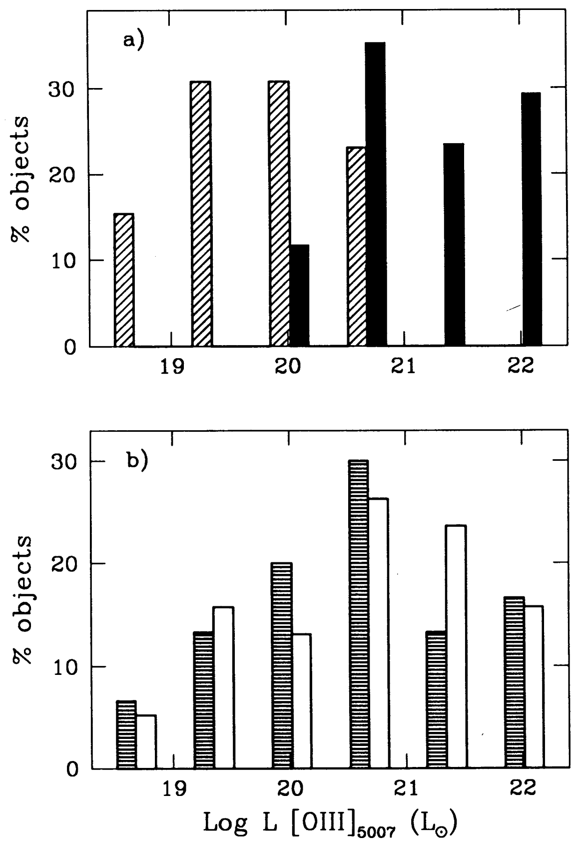

FIG. 7.—(*a*) Distribution of the [O III] luminosity for Seyfert 1–1.5 (*filled bars*) and for intermediate 1.8–1.9 Seyfert galaxies (*shaded bars*); note the lower luminosity of intermediate Seyfert galaxies with respect to Seyfert 1 galaxies. (*b*) Distribution of the [O III] luminosity for Seyfert 2 (*empty bars*) and broad-line Seyfert galaxies (1 + 1.2 + 1.5 + 1.8 + 1.9).

As outlined by Goodrich (1995) and Rudy, Cohen, & Ake (1988), some Seyfert 1.8–1.9 galaxies do not fit the extinction model; in addition, in some face-on intermediate Seyfert galaxies the 100 pc scale obscuring material is likely to be distributed in a different way from the simple model that we have proposed. However, we believe that in an unbiased sample, which includes the whole range of nuclear activity, the majority of intermediate Seyfert 1.8–1.9 galaxies can be framed in the model depicted in Figure 6.

Finally, according to the model we outlined in this section, the light cones would be defined by the shadows of both the inner and the outer torus. Thus, when estimating the expected average opening angle of the light cones by comparing with the fraction of different Seyfert types, the ratio of type 1–1.5 to type 1.8 + 1.9 + 2 has to be used, as we have indeed done in § 2.6.

4. CONCLUSIONS

We have defined a spectroscopically selected sample of nearby Seyfert galaxies to examine the biases against low-luminosity Seyfert nuclei and Seyfert nuclei in edge-on galaxies that occur in other samples that are more distant and/or are based on selection criteria that emphasize luminous AGNs. The average distance of the objects in the sample is about 30 Mpc. The relative proximity makes their nuclear spectra little contaminated by the stellar light of the host galaxy. As a consequence, the bias against low-luminosity nuclei is much reduced in our sample. Another consequence is the recovery of Seyfert nuclei in edge-on galaxies, which are missing in most other Seyfert samples.

As a result of the inclusion of low-luminosity nuclei, the occurrence of the Seyfert phenomenon amongst galaxies is found to be higher than previously estimated: the percentage of Seyfert galaxies must be higher than 5%. The bright tail of the Seyfert galaxy apparent magnitude distribution suggests that the proportion of Seyfert galaxies may be 16% ± 5%. Since Seyfert 2 nuclei are generally underluminous in the optical with respect to Seyfert 1 ones, the recovery of faint Seyfert nuclei causes the Seyfert 2 to Seyfert 1 ratio to be higher than found in previous studies: we estimate the ratio to be about 4.

The much reduced bias against edge-on Seyfert galaxies allows us to study the properties of the Seyfert nucleus versus the inclination of the host galaxy. We find types 1 + 1.2 + 1.5 to occur mostly in face-on systems, while intermediate types (1.8 + 1.9) are mostly distributed in edge-on galaxies. Such findings are consistent with a geometry according to which the inner parsec-scale torus, postulated by the unified model, completely obscures the BLR along certain lines of sight, making the spectrum look Seyfert 2–like; the outer 100 pc scale torus *coplanar* with the host galaxy, postulated by McLeod & Rieke (1995), is responsible for partial obscuration of both the NLR and BLR along the line of sight lying close to the galactic plane (axial ratio <0.6), making the narrow lines appear fainter and the spectrum appear to be of type 1.8 + 1.9, if a suitable orientation of the inner torus is present.

Finally, we find the [O III] λ5007 luminosity to be systematically lower in intermediate 1.8 + 1.9 types than in 1–1.5 types, in agreement with the expected existence of 100 pc scale material obscuring the NLR and thus responsible for the differences between these two Seyfert classes.

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APPENDIX

A1. SAMPLE SELECTION

The sample used in this paper contains the 91 galaxies with $B_T < 13.4$ known to have Seyfert characteristics, based on spectra reported in the literature and a uniform set of criteria for classification as a Seyfert nucleus, as described below. To assemble the sample, we first found all the Seyfert galaxies in the Revised Shapley-Ames (RSA) catalog (Sandage & Tammann 1987, hereafter ST87). The RSA selects galaxies having $B_T < 13.31$ ($m_{pg} < 13.2$) over the whole sky, when allowance is made for the absorption in the galactic plane. The RSA sample is known to be incomplete above 12.3 mag (Sandage et al. 1979). ST87 report a list of additional galaxies, mostly drawn from the Zwicky catalog (corrected for systematic differences in the sample magnitude scales), which have $B_T < 13.4$ and which thus should have been included in the RSA but were not. The additional objects provide a more complete sample in the sky region $\delta > -3°$ (the Zwicky catalog limit). We found 11 more Seyfert galaxies with $B_T < 13.4$ that are not in the RSA or in the additional list from ST87. Finally, the Galactic extinction makes the limiting magnitude of the survey near the Galactic plane lower than its nominal value (13.4). We attempted to recover this deficiency by looking for Seyfert galaxies which have $B_T > 13.4$ but which when corrected for galactic extinction are brighter than the limiting magnitude. Our total sample therefore consist of four nested subsamples:

Sample A (Table 2A) contains 62 Seyfert galaxies in the RSA.

Sample B (Tables 2A–2B) contains all the objects in sample A and all 13 additional Seyfert galaxies from ST87's extension to the RSA.

Sample C (Tables 2A–2C) adds 11 other Seyfert galaxies not included in the RSA or in ST87's additional list but which still have $B_T < 13.4$. Most of these objects are from the southern hemisphere.

Sample D (Tables 2A–2D) adds five more Seyfert galaxies having $B_T > 13.4$, but for which the magnitude corrected for Galactic extinction falls below 13.4. This (total) sample D contains 91 objects.

These four samples have increasing completeness (in terms of the $\langle V/V_{max} \rangle$ test) but probably also increasing selection effects; that is, they range from well-studied but incomplete samples (RSA) toward increasingly complete but poorly studied samples.

In assembling these samples, we used a number of approaches to assmble a list of candidate Seyfert galaxies. We drew from the RC3 catalog all the galaxies whose B_T was below 14.00 and selected all those classified as Seyfert galaxies by NED and meeting our other criteria, as discussed below. A second approach was to select each object classified as Seyfert in either the Véron-Cetty & Véron (1993) or in the Hewitt & Burbidge (1991) catalogs that matches the requirements for samples A–D. We also searched generally in the literature to find objects whose nuclear spectra might match our definition for a Seyfert nucleus.

Having assembled a list of candidate galaxies, we checked the Seyfert classification of each object. For this purpose, we needed a precise definition of Seyfert galaxy. For galaxies with broad permitted lines, we follow Whittle (1992) in using the [O III] λ5007/Hβ ratio as a differentiator for the subclassifications. The definition of type 2 Seyfert galaxy is based on the diagnostic ratios of Veilleux & Osterbrock (1987). (Hereafter [O III] ≡ [O III] λ5007, [N II] ≡ [N II] λ6584, [O I] ≡ [O I] λ6300, and [O II] ≡ [O II] λ3727.) Thus, we have the following definitions:

Seyfert 1.—Objects showing broad Hβ emission line and with [O III]/Hβ < 0.3.

Seyfert 1.2.—Objects showing broad Hβ and with 0.3 < [O III]/Hβ < 1.

Seyfert 1.5.—Objects showing broad Hβ and with 1 < [O III]/Hβ < 4.

Seyfert 1.8.—Objects showing broad Hβ and with 4 < [O III]/Hβ.

Seyfert 1.9.—Objects not showing broad Hβ, but having broad Hα; in these cases we check also the diagnostic ratios of the emission lines as specified in the Seyfert 2 definition (see below).

Seyfert 2.—Objects lying in the AGN region in the Veilleux & Osterbrock (1987) diagnostic diagram (defined by their solid lines) and having [O III]/Hβ > 3 to exclude LINERs. These diagnostic diagrams provide an almost extinction independent classification tool.

The division between LINERs[12] and Seyfert galaxies is not sharp. In addition, some Seyfert galaxies have a substantial contribution to their spectra from starforming activity in their host galaxies. Thus in Table 2 we mark with an "m" (*marginal*) objects that fall near the boundary of the defining line ratios, and we discuss them in § A2. A few galaxies that are traditionally classified as LINERs, such as NGC 2639 and NGC 3031, are included as Seyfert galaxies in our sample because of the criteria we used for selection. From their placement in the spectral diagnostic diagrams, these galaxies are very likely to be excited by power law spectra (Ho, Filippenko, & Sargent 1993) and hence to be associated appropriately with the Seyfert phenomenon.

Not enough data are available in the literature to locate a few type 2 Seyfert galaxies in the diagnostic diagram; we mark these cases with "i" (*incomplete*) and in § A3 we provide additional information about their activity.

[12] The definition of LINERs is given by Heckman (1980) as those objects with [O II]/[O III] ≥ 1 *and* [O I]/[O III] ≥ $\frac{1}{3}$. Note that this definition is extinction dependent.

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TABLE 2

LIST OF THE SOURCES DEFINING THE NESTED SAMPLES

Name	Type	B_T	Comments[a]	References
A. RSA Galaxies				
NGC 788	2	13.00		1, 2
NGC 1068	2	9.61		3
NGC 1097	1	10.16	v	4
NGC 1241	2	12.66		5
NGC 1275	1.9	12.35		6, 7, 8
NGC 1358	2	13.00		9, 10
NGC 1365	1.8	10.21		11, 12, 13
NGC 1386	2	12.00		9, 10
NGC 1566	1.5	10.21		14
NGC 1667	2	12.75		6
NGC 2639	1.9	12.65	m	6, 8, 15
NGC 2992	1.9	12.80		14, 16, 17
NGC 3031	1.8	7.86		6, 18, 19
NGC 3081	2	12.68		20
NGC 3185	2	12.95		21
NGC 3227	1.5	11.55		22, 23
NGC 3281	2	12.62		9
NGC 3516	1.2	12.40		22, 23
NGC 3783	1.2	12.89		14, 24
NGC 3982	2	11.91		9
NGC 4051	1.5	10.93		25
NGC 4151	1.5	11.13		22, 23
NGC 4235	1	12.62		24
NGC 4258	1.9	8.95		8, 21, 26, 27
NGC 4388	2	11.83		3
NGC 4395	1.8	10.69		28
NGC 4501	2	10.38		3, 21
NGC 4507	2	12.81		9, 20
NGC 4579	1.9	10.56		8, 15, 29
NGC 4593	1	11.72		24, 30, 31
NGC 4594	1.9	9.28		8, 15
NGC 4639	1.8	12.19		32
NGC 4941	2	11.90		21, 33, 34
NGC 4939	2	11.90		3
NGC 4945	2	9.60	i	35, 36
NGC 5005	2	10.64	m	19, 21, 23
NGC 5033	1.9	10.63		37
NGC 5128	2	7.89		3, 38
NGC 5135	2	12.94		9
NGC 5194	2	8.98		21, 26, 39
NGC 5273	1.9	12.42		37
NGC 5347	2	13.40	i	40, 41
NGC 5427	2	12.07		42
NGC 5548	1.2	13.15		22, 23
NGC 5643	2	10.89		9, 24
NGC 5728	2	12.10		9
NGC 5899	2	12.60		21
NGC 6221	2	11.52	m	43, 44, 45
NGC 6300	2	11.04		3, 9
NGC 6814	1.5	12.02		14
NGC 6890	2	13.02		9
IC 5063	2	13.22		9, 46, 47
IC 5135	2	12.92		9
NGC 7213	1.5	11.18		14
NGC 7314	1.9	11.65		21
NGC 7410	2	11.30		3, 43
NGC 7469	1.2	12.60		22, 24
NGC 7479	2	11.70		6
NGC 7496	2	11.78	m	48
NGC 7582	2	11.46	m	3, 13
NGC 7590	2	12.20		49, 50
NGC 7743	2	12.08		3, 6
B. ST87 Galaxies				
NGC 513	2	13.10		1, 2
UGC 3478	1.2	13.10		51
NGC 2273	2	12.55		1, 52
NGC 3362	2	13.20		37, 49
NGC 3786	1.8	13.10		53
NGC 4253	1.5	13.30		23
CIRCINUS	2	12.10		54
NGC 5506	1.9	12.79		55, 56, 57
NGC 5674	1.9	13.30		37
NGC 5953	2	13.06		58, 59
NGC 7172	2	12.85		49
NGC 7214	1.2	13.33		14
NGC 7465	2	13.31	m	60, 61
C. Other Seyfert Galaxies with $B_T < 13.4$				
NGC 1320	2	13.32		62
NGC 1433	2	10.70		50
IRS 07145−2914	2	13.28		63
Mrk 10	1	13.34		64
IC 2560	2	12.53	i	65
NGC 3393	2	13.10		66
IRS 11215−2806	2	13.00		51
TOL 1238−364	2	13.00		67
NGC 4785	2	13.20		65
IRS 18325−5926	1.8	13.20		68, 69
Mrk 509	1.2	13.00		14, 24
D. Seyfert Galaxies with $B_T < 13.4$ after Magnitude Correction				
Mrk 1066	2	13.64		70
Mrk 1073	2	13.70		71
NGC 2110	2	14.00		34
ESO 377−G24	1	13.54		72
ESO 323−G77	1	13.58		14

[a] "m" = marginal, "i" = incomplete data set for the diagnostic diagrams, "v" = Seyfert type has changed over time.

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In Table 2 we list (1) galaxy name, (2) Seyfert type, (3) B_T magnitude (from ST87 or from RC3 [de Vaucouleurs et al. 1991]), (4) comments ("m" = marginal, "i" = incomplete data set for the diagnostic diagrams, "v" = the Seyfert type has changed over time), and (5) references for the data used for the classification.

The RSA is quite a well-studied sample, and good quality spectra have been obtained for virtually all members. Optical spectra have also been obtained for virtually all the objects in the RC3. Nonetheless, in common with all other samples of Seyfert galaxies, some residual incompleteness is present; such problems are discussed in § 2.4. The most serious problem appears to be the inability of existing spectra to identify faint Seyfert nuclei; we show in the body of the paper that our sample is a forward step in this area, but additional work is required to achieve a large sample that is totally unbiased in nuclear luminosity.

In some objects, the Seyfert subclassification is related to the spectroscopy aperture; more specifically, the classification might move from intermediate types toward type 1 when using smaller aperture sizes (i.e., smaller extranuclear light in the beam). We checked whether such an effect might have systematically affected the subclassification in our sample, by studying the distribution of the spectroscopy aperture size (projected on the source) for different Seyfert types. We found no correlation between the Seyfert classification and the projected aperture size, thus supporting the Seyfert subclassification in our sample as mostly due to intrinsic properties of the nucleus.

However, not all the spectra have the same signal-to-noise ratio, and in some Seyfert 2 galaxies the presence of broad wings of Hα and Hβ might have been overlooked. Thus, the ratio of Seyfert 2 to Seyfert 1.9 + 1.8 might be overestimated. On the other hand, Seyfert 1–1.5 galaxies are very unlikely misclassified as Seyfert 2 (if there are no intrinsic type changes over time); thus, the Seyfert 1 + 1.2 + 1.5 to Seyfert 1.8 + 1.9 + 2 ratio should be reliable.

A2. MARGINAL CASES

NGC 2639.—Ho et al. (1993) give [N II]/Hα ∼ 2 and [O III]/Hβ = 3.32; [O II]/[O III] agree with the definition of LINER, but the [O I]/[O III] falls short by 30% (even more if extinction is present). Filippenko & Sargent (1985) and Keel (1983a) detect a broad component of Hα.

NGC 5005.—HB92 classify this galaxy as a LINER. The [N II]/Hα ratio is greater than 2 in all the references, but the [O III]/Hβ ratio is somewhat controversial: Stauffer (1982) gives 3.3, Dahari & De Robertis (1988) give 5.7, while Shuder & Osterbrock (1981) give 2.6.

NGC 6221.—In Véron-Cetty & Véron (1986b), [N II]/Hα = 0.5, but [O III]/Hβ = 0.6. From the [O III] and Hβ profiles, Véron, Véron, & Zuidervijk (1981a) claim evidence for a superposition of a starburst and a Seyfert component. The same conclusion is reached by Pence & Blackman (1984) from studies of the trend of the [O III]/Hβ ratio with the velocity field. After subtracting the stellar continuum, Bonatto, Bica, & Alloin (1989) find evidence for broad components both in the Hα and Hβ profiles; the ratios of the narrow component to [N II] and [O III] are much nearer to the typical Seyfert values ([N II]/Hα ∼ 2 and [O III]/Hβ ∼ 2).

NGC 7496.—Bonatto et al. (1989) give [O III]/Hβ = 0.69, [N II]/Hα = 0.46 and [O I]/Hα = 0.08. Véron et al. (1981b) detect the He II λ4686 line (−0.04 × Hβ), quite typical of Seyfert nuclei. From the profile of the [O III] and Hβ lines, they also claim evidence for a superposition of a starburst and a Seyfert component having different redshift line systems; for the Seyfert component [O III]/Hβ = 3.6.

NGC 7582.—Véron-Cetty & Véron (1986b) give [O III]/Hβ = 3 and [N II]/Hα = 0.7; [O I]/[O III] disagree with the LINER definition. However, other references give lower values of the [O III]/Hβ ratio: 2.9 (Penston et al. 1984), 2.5 (Dahari & De Robertis 1988), and 2.4 (Bonatto et al. 1989). Storchi-Bergmann & Bonatto (1991) find ionization cones typical of Seyfert 2 galaxies.

NGC 7465.—Osterbrock & Pogge (1987) give (extinction corrected) [O III]/Hβ = 3.18, [N II]/Hα = 0.52, and [O I]/Hα = 0.11. From the line profiles, Maehara & Noguchi (1988) claim a superposition of an AGN and a LINER spectrum.

A3. OBJECTS WITH INCOMPLETE DATA SETS

IC 2560.—Fairall (1986) gives [O III]/Hβ = 14 but no information about low-ionization lines. The [O III]/Hβ is too high even for the lowest metallicity H II regions; thus, the Seyfert classification should be solid.

NGC 4945.—Whiteoak & Gardner (1979) give [N II]/Hα = 3. Strong obscuration prevented detailed studies in the blue spectral region; in particular, no information is available for the [O III] and Hβ lines. The Seyfert classification is supported by the detection of X-ray variability on timescales of hours (Iwasawa et al. 1993).

NGC 5347.—No data are available about the line ratios of this object. HB92 classify it as a type 2 Seyfert galaxy, but they do not explicitly describe the criterion they choose for the classification; they refer to Osterbrock (1987), and thus their criterion is likely to be consistent with ours. Sandage (1978) reports "[O III] ≫ Hβ," but no quantitative information is given.

A4. OTHER GALAXIES OF INTEREST

NGC 1097.—This object was originally classified as a type 2 Seyfert galaxy according to its diagnostic ratios, with no evidence for any broad component. However, Storchi-Bergmann, Baldwin, & Wilson (1993) detect a double-peaked broad component both in Hα and in Hβ. According to the [O III]/Hβ ratio, we classify this galaxy as a type 1 Seyfert, bearing in mind that the type has changed over time.

NGC 3031.—This object has often been classified as a LINER (e.g., HB92). However, Ho et al. (1993) give [O III]/Hβ = 4.67 and [N II]/Hα ∼ 2, while the (reddening-corrected) [O II]/[O III] ratio is 0.34, i.e., not compatible with the LINER definition. Shuder & Osterbrock (1981) give lower values, [O III]/Hβ = 2.86 and [N II]/Hα = 1.82, but they also find evidence for broad Hα. Filippenko & Sargent (1988) find evidence for both a broad Hα and a broad Hβ component. They also give the following diagnostic ratios for the narrow components: [O III]/Hβ = 4.2 and [N II]/Hα = 2.2. Rapid nuclear X-ray variability typical of AGNs has been detected by Barr et al. (1995) and Barr & Mushotzky (1986).

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NGC 4579.—This object has been classified as a LINER as well. All the low ionization ratios ([N II], [S II], [O I]/Hα) are high (Goodrich & Keel 1986). The Hβ is not detected even after subtraction of the stellar continuum, consistent with an [O III]/Hβ ratio larger than 3 (Keel 1983b). Both Keel (1983b) and Filippenko & Sargent (1985) detect broad wings of the Hα. A compact nuclear radio source has been found by Hummel et al. (1985). It also has fairly strong X-ray emission (Halpern & Steiner 1983).

A5. DISCARDED OBJECTS

Some galaxies with $B_T < 13.4$ (Galaxy extinction corrected) have been classified as Seyfert galaxies, but we could not find sufficient data in the literature to support the classification; among these we report ESO 137−G34 and ESO 139−G12 (Fairall 1988a).

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