Stellar and Dust Properties of Local Elliptical Galaxies: Clues to the Onset of Nuclear Activity

(Research Note)

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ABSTRACT

Aims. We study the stellar and dust properties of a well-defined sample of local elliptical galaxies to investigate the relationship between host galaxy properties and nuclear activity.

Methods. We select a complete sample of 45 ellipticals from the Palomar spectroscopic survey of nearby galaxies, which includes 20 low-luminosity active galactic nuclei classified as LINERs and 25 inactive galaxies. Using a stellar population synthesis method, we compare the derived stellar population properties of the LINER versus the inactive subsamples. We also study the dust and stellar surface brightness distributions of the central regions of these galaxies using high-resolution images obtained with the Hubble Space Telescope.

Results. Relative to the inactive subsample, ellipticals hosting LINERs share similar total optical and near-infrared luminosity, central stellar velocity dispersions, and nuclear stellar populations as judged from their luminosity-weighted ages and metallicities. LINERs, on the other hand, have a larger fraction of core-type central surface brightness profiles and a much higher frequency of circumnuclear dust structures.

Conclusions. Our results support the suggestion that LINERs are powered by low-luminosity AGNs rather than by young or intermediate-age stars. Nuclear activity in nearby elliptical galaxies seems to occur preferentially in those systems where sufficient cold interstellar material has managed to accumulate, perhaps via cooling condensations from hot gas.

Key words. ellipticals: active-galaxies: stellar-content

1. Introduction

Supermassive black holes (SMBHs) are ubiquitous in elliptical galaxies. The discovery of a tight correlation between black hole mass and the stellar velocity dispersion of the bulge of the host galaxy (Gebhardt et al. 2000; Ferrarese & Merritt 2000) suggests that the formation and growth of central black holes are an integral part of the formation of galactic bulges. However, the majority of SMBHs in nearby ellipticals are not very active. In the Palomar spectroscopic survey of nearby galaxies (Ho et al. 1995, 1997a), only about 50% of the ellipticals show detectable emission-line nuclei, most of which (~87%) are classified as low-ionization nuclear emission-line regions (LINERs; Heckman 1980, see Ho 2008 for a review).

The physical origin of LINERs has been intensively debated. A variety of recent observations, however, provided convincing evidence that LINERs are low-luminosity active galactic nuclei (AGNs). This includes the detection of broad Hα emission (Ho et al. 1997b), some of which show double-peaked profiles (Ho et al. 2000; Shields et al. 2000; Barth et al. 2001) or are polarized (Barth et al. 1999a,b), ultraviolet variability (Maoz et al. 2005), compact X-ray cores (e.g., Ho et al. 2001; Terashima & Wilson 2003), and compact radio cores (e.g., Nagar et al. 2005). Ho (2008) suggests that nearly all LINERs are genuine AGNs with low accretion rates.

The low accretion rates of the SMBHs in nearby ellipticals probably stem from the lack of enough cold gas to fuel the central engine, as it is generally accepted that nearby elliptical galaxies contain mostly old stars and not much cold interstellar material. However, apart from the high detection rate of nuclear optical emission lines in spectroscopic surveys (Phillips et al. 1986; Ho et al. 1997a), Hα + [N II] narrow-band imaging has shown that elliptical galaxies certainly have plenty of extended warm (~ 10^4 K) gas (e.g., Shields 1991). By coadding images from the Infrared Astronomy Satellite survey scans, Knapp et al. (1989) show that ~50% of ellipticals contain cool dust. Temi et al. (2004) find that in 16 elliptical galaxies observed with the Infrared Space Observatory the dust masses are on average 10 times larger than those previously estimated from Infrared Astronomy Satellite observations. Most recently, Kaneda et al. (2005) even detected polycyclic aromatic hydro-
carbon emission features in four elliptical galaxies with the Spitzer Infrared Spectrograph. All these results suggest that the presence of a significant amount of interstellar material in elliptical galaxies is quite common, although its origin is still uncertain.

We attempt to determine the factor(s) that control the onset of nuclear activity by comparing the stellar population, central light distribution, and dust content for ellipticals with different levels of nuclear activity drawn from the Palomar spectroscopic survey of nearby galaxies (Ho et al. 1995, 1997a). This paper is organized as follows. The sample and analysis method are described in Section 2; the results of the stellar population synthesis are presented in Section 3; the discussion and conclusions are given in Section 4.

2. Sample and Method of Analysis

The sample for this study was selected from the Palomar optical spectroscopic survey (Ho et al. 1995, 1997a), which comprises all nearby galaxies brighter than $B_T = 12.5$ mag in the northern hemisphere. It presents a fair representation of the local galaxy population. This is an ideal sample because it is statistically complete and contains both active ellipticals and inactive objects, drawn self-consistently from the same parent sample, that can serve as a control sample. The optical spectra are described in detail in Ho et al. (1995). Two spectra are available for each galaxy: the blue section covers ∼ 4230 − 5110 Å with a FWHM spectral resolution of 4 Å, and the red section covers ∼ 6210 − 6860 Å with a FWHM resolution of 2.5 Å. We select all ellipticals from the parent sample classified as either LINERs according to the criteria laid out in Ho, Filippenko & Sargent (1997a) or absorption-line (inactive) sources. We reject NGC 6702 because it only has the red spectrum, and two spheroidals (NGC 147 and NGC 205) because they have a different formation history than normal ellipticals (Kormendy 1985). We include NGC 221 (M32), even though its absolute B-band magnitude is less than −18 mag, because it shares properties similar to those of normal ellipticals (Kormendy 1985; Ferguson & Binggeli 1994). Since the vast majority of the active sources are LINERs, we further removed 4 Seyferts and 5 transition objects. The final sample, whose global properties are summarized in Table 1, comprises 20 LINERs and 25 inactive ellipticals.

We modeled the stellar population of our sample using a modified version of the spectral population synthesis code, starlight1 (Cid Fernandes et al. 2004; Gu et al. 2006). The code does a search for the best-fitting linear combination of 45 simple stellar populations (SSPs)—15 ages and 3 metallicities (0.2 Z⊙, 1 Z⊙, 2.5 Z⊙)—provided by Bruzual & Charlot (2003) to match a given observed spectrum $O_i$. The model SSP spectra cover 3200 Å to 9500 Å with a FWHM spectral resolution of ∼ 3 Å (Bruzual & Charlot 2003, BC03 hereafter). The synthesized spectrum is given by (Cid Fernandes et al. 2004):

$$M_i = M_{bd} \left( \sum_{i=1}^{N} x_i b_i \lambda_i \right) \otimes G(v_i, \sigma_v),$$

where $M_i$ is the synthesized spectrum, $M_{bd}$ is the synthesized flux at normalization wavelength $\lambda_0$ (4750 Å in this work), $x_i$ is the contribution of the $i$th SSP, $b_i \lambda_i$ is the spectrum of the $i$th SSP normalized at $\lambda_0$, and $r_i = 10^{-0.4(A_{V}-A_{\lambda_0})}$ is the reddening term. The Cardelli et al. (1989) extinction law with $R_V = 3.1$ is adopted. $G(v_i, \sigma_v)$ is the line-of-sight stellar velocity distribution, modeled as a Gaussian distribution centered at $v_i$ and broadened by dispersion $\sigma_v$. The match between the model and the observed spectrum is calculated by

$$\chi^2(x, M_{bd}, A_V, v_i, \sigma_v) = \sum_{i=1}^{N} [(O_i - M_i)w_i]^2,$$

where the weight $w_i$, is defined as the inverse of the noise of $O_i$.

In order to account for the possibility of a weak AGN continuum (see Sec. 5.1 of Ho 2008), we add an additional power-law (PL) component ($f_\nu \propto \nu^{-1.5}$) during the fitting. Our fitting results show that, with the exception of NGC 315 and NGC 3193, the contribution from this PL component is negligible (less than 2%). Strong emission lines, such as Hβ, [O III] $\lambda\lambda 4959, 5007$, Ha, and [N II] $\lambda\lambda 6548, 6583$, are masked during the fitting process. The fitting procedure automatically determines a best-fitting stellar velocity dispersion ($\sigma_v$), taking into account the instrumental resolutions of both the Palomar and model library spectra. Cid Fernandes et al. (2004) estimate that the $\sigma_v$ values derived from the code has a typical uncertainty of $\sim 20$ km s$^{-1}$.

Figures 1 and 2 show two fitting examples, for the LINER NGC 2768 and the inactive elliptical NGC 4648, respectively.

We have checked every residual spectrum, and measured the emission line fluxes for LINERs, as we used the different method to subtract the stellar contribution from the Palomar survey. We find that the difference of emission line fluxes is less than 10%, which does not change the spectral classification for our sample.

We also present the stellar extinction ($A_V$) estimated by $\text{starlight}$ for each galaxy in Table 1. We find that 6 LINERs and 4 inactive ellipticals have negative $A_V$, a problem which is ultimately due to calibration problems in STELIB and mismatches between the metallicity of the evolutionary tracks and stellar spectra in BC03.

3. Results

3.1. Distance, Luminosity, and Stellar Velocity Dispersion

The distance and absolute blue magnitude of each galaxy, taken from Ho et al. (1997a), are listed in Table 1. In Figure 3(a) we show the cumulative distribution of distance for the two subsamples. We find that LINERs and inactive ellipticals have similar distance distributions, with average distances of 29.9 and 25.7 Mpc, respectively. The LINER subsample contains the most distant object in the study, NGC 2832 at $D = 91.6$ Mpc; if we exclude this object, the average distance for the LINERs becomes 27.6 Mpc. We use the two-sample Kolmogorov-Smirnov (KS) statistical task kolmrv in IRAF2 to check whether the two subsamples are drawn from the same distribution.

1 http://www.starlight.ufsc.br/

2 IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
parent distribution. The probability of rejecting the null hypothesis that the two distributions are the same is $P_{\text{null}} = 94\%$. Thus, distance effects between the two subsamples will not introduce any significant biases into our results.

The two subsamples also have very similar total luminosities, both in the optical and near-infrared bands. Figure 3(b) shows the cumulative distributions of absolute blue magnitude. LINERs have $M_B$ ranging from $-18.96$ to $-22.24$ mag, with an average value of $-20.69$ mag, while inactive Es range from $M_B = -15.51$ to $-21.64$ mag, with an average value of $-20.11$ mag. A KS test yields $P_{\text{null}} = 38\%$. We also derive absolute magnitudes in the $K_s$ band, $M_{K_s}$, using data taken from the Two Micron All Sky Survey (Skrutskie et al. 2006). Figure 3(c) shows that the absolute $K_s$-band magnitudes of LINERs are similar to those of inactive Es: LINERs have an average $M_{K_s} = -24.54$ mag, to be compared with $M_{K_s} = -23.90$ mag for inactive Es. The near-infrared luminosity of the active sources have a slight tendency to be larger than those of the inactive sources, but a KS test yields $P_{\text{null}} \approx 5\%$, which is formally only barely statistically significant. Moreover, this conclusion is not very robust. If we exclude the two most luminous objects from the active sample (NGC 315 and NGC 2832) and the least luminous object from the inactive sample (NGC 221), the significance drops to $P_{\text{null}} \approx 14\%$.

Not surprisingly, the similarity between the two subsamples extends to the stellar velocity dispersions derived from our synthesis fitting (data in Column 6 of Table 1), whose cumulative distributions are shown in Figure 4(a). For LINERs, the velocity dispersion ranges from 144 to 331 km s$^{-1}$, with an average value of $\langle \sigma_i \rangle = 251$ km s$^{-1}$; the corresponding values for inactive Es are $90 < \sigma_i < 349$ km s$^{-1}$, with $\langle \sigma_i \rangle = 211$ km s$^{-1}$. A KS test for the full sample yields $P_{\text{null}} \approx 3\%$, but the significance drops to $P_{\text{null}} \approx 9\%$ after excluding NGC 315 and NGC 2832 from the LINER sample and NGC 221 from the inactive sample.

### 3.2. Stellar Populations

As mentioned in Section 2, our spectral library covers 15 ages and 3 metallicities, which produce a total of 45 SSPs. Here we rebin the 45 SSPs into 5 components according to age: I ($10^6 < t < 10^7$ yr), II ($10^7 < t < 10^8$ yr), III ($10^8 < t < 10^9$ yr), IV ($10^9 < t < 10^{10}$ yr), and V ($t \geq 10^{10}$ yr). We derive the light-weighted mean stellar age using the formula in Cid Fernandes et al. (2005):

$$\langle \log t_{i} \rangle_L = \sum_{i=1}^{45} x_i \log t_i,$$

where $x_i$ denotes the contribution of the $i$th SSP and $t_i$ its corresponding age. Similarly, the light-weighted mean stellar metallicity is computed from

$$\langle Z_{i} \rangle_L = \sum_{i=1}^{45} x_i Z_i,$$

where $x_i$ represents the contribution of the $i$th SSP with metallicity $Z_i$. The synthesis results are presented in Table 2. Columns (2) through (6) give the fractional light contribution from the AGN PL component and from stellar populations I–V. Columns (7) and (8) list the mean stellar age and metallicity.

Figure 5 shows the contribution of each stellar population for the LINER (upper panel) and inactive E (lower panel) subsamples. It is clear that young and intermediate-age stellar populations contribute very little to the total flux for either group. For LINERs, stellar population I, II, and III contribute only <1%, 2%, and <1%, respectively; for inactive Es, the corresponding values are 1%, 2%, and <1%. Most of the optical light is dominated by an old population. The mean contribution from stellar population IV and V are 11% and 86% for LINERs, and 20% and 76% for inactive Es.

Figure 4(b) shows the cumulative distribution of mean stellar age for LINERs and inactive Es. Their average age is 8.1 Gyr and 7.1 Gyr, respectively. The only exception is the LINER NGC 4374, which has a dominant 1.4 Gyr old stellar population that contributes 89% of the light. Our stellar population synthesis suggests that LINERs and inactive Es have very similar stellar populations, both lacking young and intermediate-age populations. A KS test yields $P_{\text{null}} = 31\%$ (68%, NGC 221 excluded). The similarity of the stellar populations of the two groups further extends to the derived metallicities (Fig. 4(c)): the average metallicity for both subsamples is $\sim 1.5 Z_{\odot}$.

### 3.3. Central Light Profile

Central surface brightness profiles carry many clues on the formation and evolutionary history of the galaxy (Faber et al. 1997; Lauer et al. 2005). We compare the surface brightness profiles of LINERs and inactive Es derived from Hubble Space Telescope (HST) images, and try to find whether there is any difference between the two subsamples. The high angular resolution of HST is crucial to derive robust central profiles of galaxies.

Lauer et al. (1995) classified the central surface brightness profiles of early-type galaxies into two types. Core galaxies have central light distributions that turnover from a steep outer profile to a shallower cusp interior to some break radius. Power-law galaxies, on the other hand, display continuously rising inner profiles down to the resolution of HST. The two classes correlate with the large-scale properties of the galaxies. Core galaxies are invariably luminous giant ellipticals that are slowly rotating and show boxy isophotes; power-law galaxies occupy more intermediate luminosities, rapidly rotate, and show disky isophotes. The physical implications of these two classes for their formation histories are discussed in detail in Faber et al. (1997).

Published HST surface brightness profiles and classifications are available for most of our sample, as documented in Table 1. Among the 16 LINERs with profile classifications, 14 (88%) are core galaxies; only one galaxy, NGC 4494, is classified as a power-law system, and another, NGC 7626, has an intermediate profile. Four (NGC 315, 2768, 3226, and 5322) are too dusty to determine their profiles reliably and cannot be...
3.4. Central Dust Content

Elliptical galaxies are traditionally viewed as structurally simple systems composed of old stars and lacking in cold gas and dust. Recent observations, especially from HST images, show unambiguous evidence that many ellipticals exhibit central dust structures (van Dokkum & Franx 1995; Tran et al. 2001; Lauer et al. 2005). Lauer et al. (2005) suggested a dust-settling sequence in early-type galaxies: the dust starts off poorly organized, then gradually settles down to the center and forms dusty rings or disks. The origin of gas and dust in elliptical galaxies is not well understood. Two possibilities are frequently discussed—an internal origin from stellar mass loss or an external origin from accretion of a gas-rich companion (Lauer et al. 2005; Sarzi et al. 2006). Although we do not have detailed kinematic information on our galaxies, they are morphologically regular and do not show obvious signs of recent interactions or mergers.

We compare the dust properties of LINERs and inactive Es in our sample. Information on the central dust properties, gathered from a literature search, is summarized in Table 1. Among the LINERs, 16 out of 20 (80%) have detected central dust structures. In stark contrast, only 2 out of 22 (9%) inactive ellipticals with suitable HST data show dust features.

Since LINER hosts seem more dusty than inactive Es, we would expect LINERs to have more stellar extinction than inactive Es. We thus correlated the stellar extinction ($A_V$) with the YEs/No dust-content information. After removing the negative $A_V$, we find there is no significant difference in $A_V$, the average of $A_V$ is 0.26 mag and 0.22 mag, for LINERs and inactive ellipticals, respectively.

4. Discussion and Conclusions

Analyzing a statistically complete sample of 45 elliptical galaxies from the Palomar spectroscopic survey of nearby galaxies, comprising 20 LINERs and 25 inactive members, we show that galaxies hosting LINER nuclei, compared to systems lacking optical evidence for nuclear activity, have very similar stellar properties, both on global and nuclear scales. Specifically, we find that the two galaxy subgroups have essentially indistinguishable total optical and near-infrared luminosities, central stellar velocity dispersions, and luminosity-weighted mean stellar ages and metallicities on nuclear ($\lesssim 300$ pc) scales. The lack of young or intermediate-age stars in LINERs strongly rule out starburst and post-starburst models for the excitation of LINER-like emission, further strengthening the proposition that LINERs are low-luminosity AGNs (Ho 2008).

Our results are qualitatively consistent with those from previous studies of the Palomar survey. Ho et al. (2003) systematically investigated the stellar population of the emission-line nuclei in the Palomar survey and found that LINERs generally contain evolved stellar populations. Other evidence concerning the the old ages of the nuclear stellar population in nearby low-luminosity AGNs is summarized in Ho (2008). Ho et al., however, did not derive detailed ages or metallicities from a population synthesis analysis. This work is the first quantitative analysis of its kind for the Palomar survey. On the other hand, studies of larger samples of LINERs drawn from the Sloan Digital Sky Survey reach somewhat different conclusions. While LINERs on average have older stars than Seyferts (Kewley et al. 2006), Graves et al. (2007) and Schawinski et al. (2007) show that LINERs have a tendency to exhibit somewhat younger populations compared to inactive early-type galaxies devoid of emission lines. The difference may arise from the following two points. First, the sources from the Sloan Digital Sky Survey have redshifts $z \approx 0.05 - 0.1$, much more distant than the Palomar galaxies. As discussed by Ho (2008), aperture effects render the interpretation of LINER emission in distant galaxies particularly ambiguous. Second, the stellar population analysis method of this paper is different from that used in SDSS galaxies. However, the reported age differences are relatively small and may require more data than we have and/or a more detailed analysis to be checked.

Surprisingly, we find that LINER host galaxies have a greater tendency to exhibit central core light profiles. Lauer et al. (2005) suggest that core galaxies are more luminous, more massive, and may be older than power-law galaxies, seemingly at odds with our results. Considering the modest size of our sample, however, and the large scatter in the statistical correlations between profile type and global properties, this disagreement is not too alarming.

By far the clearest distinction between active and inactive ellipticals is that the former has a much higher likelihood of containing circumnuclear dust. This finding is in excellent agreement with that of Lauer et al. (2005), who also found a strong correlation between the incidence of nebular line emission—which in ellipticals invariably signifies a LINER classification (Ho 2008)—and central dust features: 90% of emission-line nuclei show detected central dust structures, to be compared with just 4% for the lineless systems. Ravindranath et al. (2001) similarly suggested a connection between Hα emission and dust features, and the tendency for LINERs to be more dusty. Recently, Simões Lopes et al. (2007) presented strong evidence that circumnuclear dust is correlated with AGN activity in early-type galaxies. Among 34 early-type galaxies classified as AGNs, all show circumnuclear dust structures, to be compared with only 26% in the control sample of inactive systems.

Taken collectively, the above evidence suggests that ellipticals with weakly active, LINER nuclei are more gas-rich than their inactive counterparts. Given the lower stellar density in the cores, we actually expect less cold gas accumulation from stellar mass loss, not more, among the LINER hosts (see, e.g., Soria et al. 2006). On the other hand, massive ellipticals are surrounded by hot X-ray halos (e.g., Jones et al. 2002), whose cooling time is sufficiently short that cooling flows should develop. We speculate that the central dust features in core-type LINER ellipticals may partly originate from cooling condensations in the X-ray-emitting gas. The “extra” cold gas and dust, in combination with direct spherical accretion from the hot gas...
itself, may be responsible for sustaining the weak nuclear activity. Perhaps elliptical galaxies with LINER nuclei identify the subclass of early-type galaxies in which this mode of accretion is significant.

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### Table 1. Global and central properties

| LINERs | D (Mpc) | M_B (mag) | M_K (mag) | Class | σ_r (km s$^{-1}$) | A_V (mag) | Profile | Ref. | Dust Properties | Ref. |
|--------|---------|-----------|-----------|-------|-----------------|----------|---------|------|----------------|------|
| NGC 315 | 6.58 | −22.22 | −26.14 | L1.9 | 322 | 0.42 | Dust disk | 2 |
| NGC 1052 | 17.8 | −19.90 | −23.80 | L1.9 | 240 | 0.04 core 1,9 | Has dust | 3 |
| NGC 2768 | 23.7 | −21.17 | −24.88 | L2 | 170 | 0.32 | Spiral dust lanes | 4 |
| NGC 2832 | 91.6 | −22.24 | −26.11 | L2: | 329 | 0.02 core 1,10 | No dust | 5 |
| NGC 3193 | 23.2 | −20.10 | −23.85 | L2: | 193 | −0.02 core 1.8 | No dust | 6 |
| NGC 3226 | 23.4 | −19.40 | −23.28 | L1.9 | 227 | 0.61 | Dust disk | 2 |
| NGC 3379 | 8.1 | −19.36 | −23.27 | L2/T2:: | 237 | −0.17 core 1.4 | Dust ring or disk | 4 |
| NGC 3608 | 23.4 | −20.16 | −23.75 | L2/S2: | 218 | −0.10 core 1.4 | Dust ring or disk | 4 |
| NGC 4261 | 35.1 | −21.37 | −25.46 | L2 | 331 | 0.16 core 1.3 | Dust disk | 2 |
| NGC 4278 | 9.7 | −18.96 | −22.75 | L1.9 | 269 | −0.11 core 1.4 | Spiral dust lanes | 4 |
| NGC 4374 | 16.8 | −21.12 | −24.90 | L2 | 246 | 0.96 core 1.3 | Dust lanes | 3 |
| NGC 4486 | 16.8 | −21.64 | −25.31 | L2 | 328 | 0.04 core 1.11 | No dust | 7 |
| NGC 4494 | 9.7 | −19.38 | −22.94 | L2:: | 144 | 0.14 PL 1.8 | Dust ring or disk | 4 |
| NGC 4589 | 30.0 | −20.71 | −24.63 | L2 | 243 | 0.34 core 1.4 | Chaotic dust patches | 4 |
| NGC 4636 | 17.0 | −20.72 | −24.73 | L1.9 | 215 | 0.14 core 1.3 | Dust lanes | 7 |
| NGC 5077 | 40.6 | −20.83 | −24.83 | L1.9 | 266 | 0.04 core 1.8 | Dust filaments | 6.8 |
| NGC 5322 | 31.6 | −21.46 | −25.34 | L1.9 | 232 | −0.08 | Dust ring or disk | 4 |
| NGC 5813 | 28.5 | −20.85 | −24.86 | L2: | 257 | 0.21 core 1.4 | Dust disk | 6 |
| NGC 5982 | 38.7 | −20.89 | −24.79 | L2:: | 267 | −0.12 core 1.4 | No dust | 2,3,6 |
| NGC 7626 | 45.6 | −21.23 | −25.26 | L2:: | 286 | 0.22 int 1.3 | Dust ring or disk | 2,4 |
| average | 29.9 | −20.69 | −24.54 | L2 | 251 | 0.15 | | |
| rms | 20.1 | 0.92 | 0.99 | L2 | 50 | 0.28 | | |

Col. (5): Nuclear spectral classification from the Palomar survey (Ho et al. 1997a): L = LINER, S = Seyfert, T = transition object, and A = absorption-line nucleus (inactive). The last two rows show the average value and rms of each column. Ref: 1. Lauer et al. 2007; 2. González Delgado et al. 2008; 3. Ravindranath et al. 2001; 4. Lauer et al. 2005; 5. Martel et al. 2004; 6. Tran et al. 2001; 7. van Dokkum & Franx 1995; 8. Rest et al. 2004; 9. Quillen et al. 2000; 10. Laine et al. 2003; 11. Lauer et al. 1995; 12. Faber et al. 1997.
Table 2. Synthesis results

| LINERs   | PL (%) | I (%) | II (%) | III (%) | IV (%) | V (%) | log Age (yr) | Metallicity (Z⊙) |
|----------|--------|-------|--------|---------|--------|-------|--------------|------------------|
| NGC 315  | 7      | <1    | <1     | <1      | 92     | 9.79  | 1.29         |
| NGC 1052 | <1     | <1    | <1     | <1      | 11     | 89    | 10.03        | 1.53             |
| NGC 2768 | <1     | <1    | <1     | <1      | 37     | 63    | 9.79         | 2.07             |
| NGC 2832 | <1     | <1    | <1     | <1      | 99     | 10.11 | 1.29         |
| NGC 3193 | 9      | <1    | <1     | <1      | 91     | 9.72  | 1.12         |
| NGC 3226 | <1     | <1    | <1     | <1      | 72     | 28    | 9.79         | 1.00             |
| NGC 3379 | <1     | <1    | <1     | <1      | 99     | 10.11 | 1.68         |
| NGC 3608 | 2      | <1    | <1     | <1      | 98     | 10.05 | 1.23         |
| NGC 4261 | <1     | <1    | <1     | <1      | 95     | 10.06 | 1.49         |
| NGC 4278 | <1     | <1    | <1     | <1      | 99     | 10.07 | 1.75         |
| NGC 4374 | <1     | <1    | <1     | <1      | 90     | 8     | 9.18         | 2.46             |
| NGC 4486 | <1     | 2     | 1      | <1      | 96     | 9.99  | 0.86         |
| NGC 4494 | <1     | 1     | 7      | <1      | 83     | 9.80  | 1.25         |
| NGC 4589 | <1     | <1    | 11     | <1      | 88     | 9.76  | 2.50         |
| NGC 4636 | <1     | <1    | <1     | <1      | 99     | 10.04 | 1.00         |
| NGC 5077 | <1     | 4     | <1     | <1      | 96     | 9.96  | 1.74         |
| NGC 5322 | <1     | 1     | 12     | <1      | 88     | 9.75  | 2.50         |
| NGC 5813 | <1     | <1    | <1     | <1      | 99     | 10.11 | 1.36         |
| NGC 5982 | 1      | <1    | <1     | <1      | 98     | 9.98  | 0.99         |
| NGC 7626 | <1     | <1    | <1     | <1      | 99     | 10.11 | 1.25         |
| average  | 1.0    | 0.4   | 1.7    | <1      | 11     | 86    | 9.91         | 1.52             |
| rms      | 2.5    | 1.0   | 3.6    | <1      | 25     | 24    | 0.22         | 0.51             |

Cols. (2)–(7) list the fractional contribution to the total flux by the PL and by stellar populations I, II, III, IV, and V, respectively. Contributions less than 1% are listed as upper limits. Col. (8) gives the mean stellar age, and Col. (9) gives the mean metallicity. The last two rows show the average value and rms of each column.
Fig. 1. Synthesis results for the LINER NGC 2768. The flux is normalized at 4750 Å. The black line is the observed spectrum; the red line is the synthesized spectrum; and the green line is the residual spectrum after subtracting the synthesized spectrum from the observed spectrum. The vertical scale has been shifted arbitrarily. There are no data in the region $\sim 5110-6210$ Å.

Fig. 2. Same as Figure 1, but for the inactive elliptical NGC 4648.

Fig. 3. Cumulative distribution of (a) distance, (b) absolute blue magnitude, (c) absolute $K_s$-band magnitude for LINERs (filled circles) and inactive ellipticals (open circles).

Fig. 4. Cumulative distribution of (a) central stellar velocity dispersion, (b) mean stellar age, (c) mean stellar metallicity for LINERs (filled circles) and inactive ellipticals (open circles).
Fig. 5. The fractional contribution to the total flux of each stellar population for LINERs (upper panel) and inactive ellipticals (lower panel). The abscissa gives the logarithm of the age, where 5.5 corresponds to the AGN PL component; 6.5, 7.5, 8.5, 9.5, and 10.5 correspond to stellar populations I, II, III, IV, and V, respectively. The point and error bar to the left of each population indicate the average fraction and rms, respectively. We did not fit a PL component to the inactive ellipticals.