DEMographics of Sloan Digital Sky Survey Galaxies ALONG THE HUBBLE SEQUENCE

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ABSTRACT
We present the statistical properties of a volume-limited sample of 7429 nearby (z = 0.033–0.044) galaxies from the Sloan Digital Sky Survey Data Release 7. Our database includes morphology distribution as well as the structural and spectroscopic properties of each morphology type based on the recent remeasurements of spectral line strengths by Oh and collaborators. Our database does not include galaxies that are apparently smaller and flatter because morphology classification of them turned out to be difficult. Our statistics confirmed the up-to-date knowledge of galaxy populations, e.g., correlations between morphology and line strengths as well as the derived ages. We hope that this database will be useful as a reference.

Key words: galaxies: elliptical and lenticular, cD – galaxies: general – galaxies: spiral – galaxies: statistics – methods: data analysis
Online-only material: color figure, supplemental data (FITS) file

1. INTRODUCTION
Three-quarters of a century after the introduction of the Hubble Sequence (Hubble 1926, 1936), galaxy morphology is still a mystery and the subject of numerous studies. Morphology classification is often the first step in many galaxy-related investigations. Regarding the implications of the Hubble Sequence, galaxy morphology is considered variable, as it was in the original impression in Hubble’s scheme. However, unlike in the original impression, morphology transformation is currently considered possible in many different ways.

The original, simple, two-pronged classification has since been modified and expanded to suit additional galaxies discovered (de Vaucouleurs 1959; Sandage 1961). Based on Hubble’s tuning fork scheme, van den Bergh (1960a, 1960b, 1960c) suggested his classification, called the David Dunlap Observatory system, considering galaxy luminosity and the presence of spiral arms. In this scheme, luminosity class I galaxies are supergiants with long and well-developed spiral arms. Luminosity class III galaxies are giants with patchy arms and luminosity class V galaxies are dwarfs of very low surface brightness, showing only a hint of spiral structure. Later, van den Bergh (1976) further elaborated his scheme by adding a parallel sequence of anemic spirals and gas-free lenticular galaxies according to the amount of gas in the disk. On the other hand, Kormendy (1979) utilized additional shape parameters, such as lens (lenticular galaxies) and ring structure, as secondary classification criteria, based on 121 galaxies listed in the Second Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1976). In addition, de Vaucouleurs (1974) presented various correlations between morphology and other galaxy properties, such as luminosity, ellipticity, mass, density, spectral energy distribution, and color. It is also worth noting that Dressler (1980) conducted a study that was based on a dramatically increased number of samples.

The study, which was based on roughly 6000 bright galaxies from 55 clusters, unveiled a tight correlation between density and morphology. Later, Roberts & Haynes (1994) showed the morphological dependence of fundamental galaxy properties according to Hubble types using the Third Reference Catalogue of Bright Galaxies (RC3; de Vaucouleurs et al. 1991) and the Arecibo General Catalog. Based on these previous works, Kormendy & Bender (1996) proposed a revised version of Hubble’s tuning fork, particularly for early-type galaxies, using the velocity anisotropy that can be deduced from the isophotal shapes of galaxies. Meanwhile, Morgan (1958, 1959, 1962) developed a fundamentally different morphology classification system based on the central concentration of light. This one-dimensional classification scheme, often referred to as the Yerkes system, arranged galaxies in its a-f-g-k sequence from the weakest central concentration of light (a) to the strongest (k). The connection between morphology and the central concentration of light was later confirmed by numerous studies, including Abraham et al. (1994), Bershady et al. (2000), Shimasaku et al. (2001), and Conselice (2003).

With the advent of mega-scale surveys that provide pipeline-measured properties, further considerations of galaxy classification became possible. Studies on the Hubble Space Telescope Medium Deep Survey (Abraham et al. 1996) and the 2 degree Field Galaxy Redshift Survey (Côlless et al. 2001) were good examples, and now it is more readily possible through the Sloan Digital Sky Survey (SDSS; York et al. 2000). For example, Abraham et al. (2003) applied the asymmetry-related Gini coefficient as a new tool for galaxy morphology classification. From a different direction of effort, asymmetry and clumpiness in the galaxy image have been used to classify galaxies (e.g., Abraham et al. 1994, 1996; Conselice 2003; Lotz et al. 2004).

Another great advantage of using mega-scale surveys is that we can achieve results that are statistically more significant. The most recent SDSS database contains roughly a million galaxies, which is orders of magnitude larger than older databases. Such large modern surveys provide galaxy properties (e.g., concentration index and FracDev, as discussed in Section 3) measured in uniform ways and, therefore, make many interesting investigations possible (Bernardi et al. 2003; Schawinski et al. 2007; Lintott et al. 2008; Suh et al. 2010; Tempel et al. 2011; Gonzalez-Perez et al. 2011). Regarding the size of the database used for morphology classification, it should also be noted that Fukugita et al. (2007), Nair & Abraham (2010), and the EFIGI team (Baillard et al. 2011; de Lapparent et al. 2011) performed detailed morphology classification using the SDSS DR3, DR4, and RC3, respectively (see Section 3.2 for details).
We first performed visual morphology classification on a subsample of 500 random galaxies and found that classification is practically impossible when a galaxy is too small or has a low $\text{IsoB}_r/\text{IsoA}_r$ in appearance. Most of the non-classifiable galaxies (68\%) were located in the gray area in Figure 1. While it is admittedly subjective, we determined the demarcation lines based on the semimajor ($\text{IsoA}_r$) and semiminor ($\text{IsoB}_r$) axes of the galaxy images, as shown in Figure 1. In summary, we excluded the galaxies of size $\text{IsoA}_r < 30''$ or $\text{IsoB}_r/\text{IsoA}_r < -0.01 \text{IsoA}_r + 0.90$, after which 10,233 galaxies remained (only approximately 30\% of the initial sample). Eliminating all of the apparently small and low $\text{IsoB}_r/\text{IsoA}_r$ galaxies, our sampling inevitably suffered from a bias against such galaxies. As a result, our sample does not properly represent intrinsically low $\text{IsoB}_r/\text{IsoA}_r$, early-type galaxies, such as E5 through E7. This is an important caveat of our investigation. After extensive visual inspection of the 10,233 galaxies, we felt reasonably confident in our morphological classification of only 7433 galaxies. Our selection scheme removes 84.2\% of our “non-classifiable galaxies” and retains 81.5\% of “classifiable galaxies.” It is worth noting that none of the morphology types preferentially occupy the specific zone in Figure 1.

3. BASIC PROPERTIES OF GALAXIES

3.1. Morphology

Morphology classification was conducted using SDSS gri composite color images with two different image scales (72'' × 72'', 216'' × 216''). It should be noted that when using a fixed contrast ratio for the galaxy morphology classification, it is difficult to distinguish elliptical galaxies from S0. Color itself was not used as a classification criterion.

The existence of disk features played the most important role for distinguishing disk galaxies from elliptical galaxies. Depending on the visibility of arm structures, disk galaxies were divided into lenticular or spiral galaxies. Following the guidelines from Hubble (1926), from Sa to Sd, the spiral galaxy’s subclass was visually determined primarily by the tightness of the galaxy’s arms and the relative bulge dominance. Identification of barred spirals was also done visually and, therefore, was subject to a substantial uncertainty. We did not measure bar strength or length but just confirmed the presence of the bar through image inspection. It is interesting to note that Oh et al. (2012) claimed that visual identification is still more effective than automated techniques, at least for SDSS images. SBd galaxies were difficult to identify because they are generally smaller and fainter than earlier-type galaxies, and also because their bulges are small, and bar size usually correlates with bulge size (Oh et al. 2012). Consequently, only 18 SBd galaxies were found and the statistics for the SBd might not be reliable.

Elliptical galaxy classification was done in two steps. First, we identified the galaxies as elliptical when it showed no disk feature and a relatively continuous light profile without any clumpy structures. Second, we used $\text{IsoA}_r$ and $\text{IsoB}_r$ from SDSS in order to determine their apparent ellipticity. The $\text{IsoA}_r$ and $\text{IsoB}_r$ measurements were from the projected shapes of galaxies and, therefore, may not reflect their true shapes (Kimm & Yi 2007). Due to our sampling strategy described in Section 2, only a small number of galaxies were labeled as E5 (39), E6 (4), or E7 (0). We found it meaningless to derive mean properties for a sample with four galaxies and, therefore, removed the four E6
Figure 2. Samples of the SDSS DR7 composite images of morphologically classified galaxies in the Hubble Sequence. Each class shows three sample galaxies. (A color version of this figure is available in the online journal.)

Elliptical and S0 (and sometimes even Sa) galaxies appeared to be very similar to each other (van den Bergh 2009), which made it difficult to distinguish them from each other. For much of our analysis, we combined elliptical and S0 galaxies into “early-types” for this reason. Figure 2 shows sample galaxy images along the Hubble Sequence.

Irregular galaxies were classified by their unclear nucleus structure and their degree of broken symmetry. Some of the apparently small galaxies do not show clear features such as symmetrical spiral arms or central bulges and hence were classified as irregular.

“Unknown” galaxies are different from the non-classifiable ones. After filtering out non-classifiable galaxies through the method described in Section 2 (Figure 1), 2,894 out of 10,233 galaxies were defined as unknown by visual classification. As described in the following section, most of our unknown-type galaxies are classified as S0 by other previous investigators. The rest consists of relatively more inclined galaxies, and hence more difficult to classify, and tidally disturbed galaxies, making it difficult to determine their detailed sub-types.

Figure 3 shows the number distribution of galaxies along the Hubble Sequence. In the final sample, 22.7% (1689), 75.8% (5628), and 1.5% (112) of the galaxies were classified as early-type, late-type, and irregular, respectively. These values were more uncertain for later types of galaxies for several reasons, including the caveat in our sampling strategy. Yet, we still believe that these galaxies are useful for providing a rough idea of the true morphology mix in the local universe. The disk dominance was primarily due to the fact that our luminosity cut was fairly faint, and disk galaxies tend to be fainter on average than early-type galaxies.

We checked the reliability of our morphology classification by inspecting the concentration index and the FracDeV provided by SDSS. The concentration index has been widely used in galaxy morphology classification (Doi et al. 1993; Abraham et al. 1994, 1996; Shimasaku et al. 2001; Conselice 2003). In this study, we used the concentration index defined as the ratio between PetroR90 and PetroR50. In other words, C_r ≡ PetroR90/PetroR50, from r-band Petrosian magnitudes. A clear trend in the concentration index based on morphology is visible in Figure 4. We should point out that in this figure, and some of the following figures, we adopted the same format as for the Hubble Sequence. It should be noted that we did not include E6 or E7 for the reasons we discussed in Sections 2 and 3. Since there is virtually no notable difference among the different subclasses of elliptical galaxies, we introduced a bar called “E_tot” combining all elliptical galaxies from E0 through E5, and we placed it between the “E5” and “S0” bars. Each bar shows the median with the standard deviation and the mean (x symbols) for reference.

Elliptical galaxies had a concentration index higher than 3.0 with minimal dispersion, indicating a centrally concentrated light distribution. We did not see any notable distinction between the different subclasses of elliptical galaxies. Spiral galaxies (in the median values) showed a strong trend from Sa to Sd, which was consistent with the anticipated results from the increasing trend of the disk contribution from Sa to Sd. However, the dispersions were very large and, therefore, the statistical significance may be low.

We performed a similar exercise using FracDeV as well (Figure 5). The SDSS pipeline parameter gives the fraction of light that is attributed to the de Vaucouleurs profile as opposed to the exponential disk profile. A pure bulge will have a value of 1, while a pure disk will have a value of 0. Our early-type galaxy classifications (E0–E5) had medians of 1.0, while spiral galaxies showed smaller values. The general trends were the same as those found in the concentration index test shown in Figure 4.
Both of the tests performed based on the concentration index and FracDeV indirectly indicated that our morphology classification was sensibly performed.

3.2. Comparison with Previous Works

We show in Figure 6 a comparison of the morphology classification between select previous catalogs and ours. The top-left panel shows a one-to-one correspondence relation comparing classifications for the 566 of our objects that are in the RC3. The size of the circle denotes the fraction in each class. For an accurate cross-matching process, we used the improved coordinates of the HyperLeda database (Paturel et al. 2003). By and large, our classifications are consistent with those of the RC3 as long as they are classified by both exercises. We
are generally more conservative by putting more galaxies into the “unknown” category. Symmetrical minor discrepancies in classification are shown for (barred) spiral galaxies. This trend is consistently shown in other comparisons using the catalogs established by Fukugita et al. (2007), Nair & Abraham (2010), and Baillard et al. (2011). Even though there are only 227 galaxies in common between Fukugita et al. (2007) and our catalog, the correlation between the two catalogs is good. Based on the SDSS DR4 spectroscopic release, Nair & Abraham (2010) presented a morphological catalog for 14,034 galaxies in the redshift range $0.01 < z < 0.1$ with an apparent limit-magnitude of $g < 16$ mag. As we can expect, the SDSS-based catalog shows the largest overlap with our catalog. The catalog presented by Baillard et al. (2011), the EFIGI team, is a sub-sample of the RC3 and it naturally leads to a smaller number of cross-matched objects compared to the RC3. They classified 4458 nearby galaxies at $0 < z \lesssim 0.05$ extracted from the Principal Galaxy Catalogue with supplemental information from the SDSS DR4. Baillard et al. (2011) quantified bar length parameters using five types (0, 0.25, 0.5, 0.75, and 1). The bottom-right panel of Figure 6 was generated using a 0.25 bar length as the representative barred galaxy. We also confirm that the level of agreement between these independent classifications was very good when we used the concentration index as a reference parameter.

3.3. Color–Magnitude Diagram

Our early- and late-type galaxies populated distinctively different regions in the color–magnitude diagram, as shown in Figure 7. The early-type (E0–E5) galaxies exhibited a tight color–magnitude relationship, as has been found in numerous studies in the past (Sandage & Visvanathan 1978; Bower et al. 1992; Driver et al. 2006). Late-type galaxies are fainter and bluer on average than early-type galaxies, forming the often-called “blue cloud”. The bimodal separation is clear (Strateva et al. 2001; Blanton et al. 2003; Hogg et al. 2003); however, the distribution of barred spirals is less distinctive. A bar is found more often in earlier-type spiral galaxies (i.e., Sa and Sb) than in later-type spiral galaxies (Sc and Sd) in our volume-limited sample. Our classification is in good qualitative agreement with those of Masters et al. (2011) and Oh et al. (2012), who also used volume-limited samples.1

3.4. Stellar Mass

We estimated the stellar mass of our galaxies using $k$-corrected colors and magnitudes following the formulae developed by Bell et al. (2003) and presented in Figure 8. The median of the stellar mass was higher for early-type galaxies, as expected. The median masses of early-(E0 through E5) and late-(S(B)b through S(B)d in this case) type galaxies were $10^{11.0}$ and $10^{10.3} M_\odot$, respectively. We did not see much of a trend in stellar mass along the Hubble Sequence with the early-type galaxies. This result may imply that there is little type dependence of stellar mass among elliptical galaxies. However, this result could also be attributed to the fact that the apparent shape of elliptical galaxies does not rigorously reflect the true shape. The type dependence of stellar mass is clearer in the late-type galaxies. Again, this is probably a result of the fact that sub-classification is more straightforward for late-type galaxies. Figure 9 shows Hubble’s tuning fork for absolute magnitude.

1 There have been reports that are inconsistent with our result. For example, Barazza et al. (2008) showed that bluer galaxies have higher bar fractions. Nair & Abraham (2010) found two peaks in the bar fraction at low and high masses. However, our sample shows lower bar fractions at bluer colors and lower mass regimes. First of all, this discrepancy is partly due to the fact that detailed morphologies of low-mass and blue galaxies are difficult to determine. Our barred spiral galaxies are well matched with the “strong” and “intermediate” sub-classes of Nair & Abraham (2010). On the other hand, we tend not to classify their “weak” galaxies as barred galaxies. In addition, volume limitation significantly affects the statistics of low-mass galaxies. If we apply the same volume limitation, removing fainter galaxies from the sample, most studies agree with each other in the trends in bar fraction.
Based on magnitude-limited samples, van den Bergh (2011) found no significant difference in luminosity distribution between unbarred and barred galaxies. It is interesting to note that for a given subclass, S(B)a through S(B)d, barred galaxies tend to be heavier in our study, as recently found by Oh et al. (2012) in their in-depth study on barred galaxies. This result does not change when we use different mass estimates (e.g., the NYU-VAGC (Blanton et al. 2005) and the MPA-JHU catalog). This result may not be statistically significant as their scatters overlap based on our sample, and it calls for further investigation.

3.5. Velocity Dispersion

One of the most important differences between early- and late-type galaxies from textbooks is their kinematic status. Early-type galaxies are more pressure supported, whereas late types are more rotationally supported. SDSS provides spectra and associated stellar velocity dispersions for most of its galaxies. We adopted the new measurements of velocity dispersions from the OSSY database (Oh et al. 2011). The OSSY team remeasured the velocity dispersions based on their improved spectral fits to the observed spectra. The difference between the SDSS pipeline values and the OSSY values was minor, but more obvious at low values (see Figure 6 of Oh et al. 2011), which indicated that the velocity dispersions we used were

\[ \text{N} = 566 \]

\[ \text{N} = 227 \]

\[ \text{N} = 2818 \]

\[ \text{N} = 373 \]
spiral galaxies (dot-dashed lines, bottom). Gray contours show the 1 effective radius of each galaxy and derived measurements are prone to many uncertainties, values that are smaller than this range are extremely difficult to measure realistically and values that are larger than this range are thought to be unrealistic. Roughly 10% of S(B)c, 28% of S(B)d, and 10% of irregular galaxies were eliminated by this cut. Therefore, some of our final galaxy samples do not appear in this figure.

The median and mean values of sigma are shown in Figure 10. Early-type galaxies had larger velocity dispersions further for the effective radius of each galaxy and derived $\sigma_{\text{eff}}$ using the formulae from Cappellari et al. (2006) and Graham et al. (2005). We adopted the values only when $10 < \sigma_{\text{eff}} < 400 \text{ km s}^{-1}$. The reason for this range is that, while velocity dispersion measurements are prone to many uncertainties, values that are smaller than this range are extremely difficult to measure realistically and values that are larger than this range are thought to be unrealistic. Roughly 10% of S(B)c, 28% of S(B)d, and 10% of irregular galaxies were eliminated by this cut. Therefore, some of our final galaxy samples do not appear in this figure.

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4. ABSORPTION-LINE STRENGTHS

In this section, we provide the characteristic properties of the stellar absorption-line strengths of our galaxies based on the OSSY database (Oh et al. 2011). The OSSY team measured the absorption-line strengths from emission-cleaned spectra with the standard line strength definition. Before measuring the strengths, the SDSS spectra were set to the rest frame and de-graded to the Lick/IDS system resolution. Also, they corrected the stellar kinematic broadening by taking into consideration the optimal combination of the stellar templates and the emission-subtracted ganda1f fit. In addition, when the telluric lines fell into the pseudocontinuum or index passbands, the line index values were replaced by the values of the stellar optimal fit in order to avoid meaningless index strengths from unacceptable fits. We used quality-assessing parameters that were smaller than 2 in the OSSY catalog, which guaranteed the reliability of the continuum fitting process within 2$\sigma$ at all of the signal-to-noise-ratio (S/N) regimes. In other words, we only used the galaxies for which the continuum fits were achieved with good confidence. By using this criterion, roughly 3%–5% of galaxies from each morphology class were eliminated, with the exception of S(B)d (5%–15%) and irregulars (5%–8%). The dramatic rejection rate of S(B)d and irregulars was a result of being faint and, therefore, it led to a low S/N compared to other types. As a result, we presented 7252 (97.6%), 7173 (96.5%), and 7204 (96.9%) galaxies for H$\beta$, Fe5270, and Mgb index strengths, respectively.

4.1. H$\beta$

Balmer absorption lines are widely used as a galaxy age indicator due to their high sensitivity to age, but not to metallicity (Worthey 1994). H$\beta$ is preferred in particular for its good strength and convenient wavelength. It peaks around A-type stars whose photosphere is roughly 10,000 K degrees and, therefore, it is very useful for deriving the ages of stellar populations older than 100 Myr whose turn-off temperature roughly corresponds to the A type.

Figure 11 shows the equivalent width of the H$\beta$ absorption-line strength. Elliptical galaxies have small H$\beta$ values (median $\pm 0.25$ Å), while spiral galaxies have large values ($2.77^{+0.77}_{-0.77}$ Å). This measurement is consistent with previous studies (Tantalo et al. 1998; Bernardi et al. 2006; Kuntschner et al. 2006; Ganda et al. 2007) in the 1$\sigma$ range. The larger values of the late-type galaxies indicate relatively younger luminosity-weighted ages. A good trend among the late-type galaxies along the Hubble Sequence is also consistent with the general expectations. However, a more realistic interpretation requires taking the variation of metallicity into consideration as well, which will follow in Section 4.4.

4.2. Fe5270

The metallicity of a galaxy holds important information about its formation history. The fact that more massive galaxies are more metal rich is generally interpreted as a result of chemical recycling, which is affected by the size of the gravitational potential well of the galaxy (Larson 1974). Elliptical galaxies are generally more massive than spirals, as discussed in Sections 3.3 and 3.4, and it is also believed that they have had more effective recycling of metals through shorter starbursts, and, therefore, these galaxies are expected to have a higher metal abundance.

We inspected the classical metallicity indicator, the Fe5270 index. Our cursory inspection shown in Figure 12 confirms our expectation that massive elliptical galaxies have stronger Fe5270 strengths and that the Fe5270 strength decreases among the late types along the Hubble Sequence (from S(B)a to S(B)d). The type dependence of Fe5270 and other lines (Mgb and H$\beta$ in the following sections) is partly due to the type–mass trend but is still visible even for fixed masses. As mentioned in Section 4.1, however, the age and the metallicity of a galaxy both
affect the Fe5270 index. Therefore, estimating the metallicity of a galaxy solely based on Fe5270 is not feasible. We should constrain the age and metallicity parameters simultaneously instead (González 1993; Fisher et al. 1996; Jørgensen 1999; Kuntschner 2000; Trager et al. 2000a). We will discuss this further in Section 4.4.

4.3. Mgb

The Mgb index is generally considered to be a good tracer of the $\alpha$ particle abundance. The $\alpha$-to-iron ratio, $[\alpha/\text{Fe}]$, is thought to be indicative of the star formation history of the stellar population. While Fe is produced primarily by Type Ia supernova explosions, Mg, which is the most representative $\alpha$ element, is produced by both Type Ia and II supernovae (Tinsley 1979; Nomoto et al. 1984; Woosley & Weaver 1995; Thielemann et al. 1996). Since it takes longer for a stellar population to produce Type Ia supernovae than to produce Type II supernovae, the duration of the galactic-scale star formation history directly determines the value of $[\alpha/\text{Fe}]$ (e.g., Greggio & Renzini 1983; Matteucci & Greggio 1986; Matteucci & Tornambe 1987; Pagel & Tautvaisiene 1995; McWilliam 1997). In this line of thought,
the Hubble Sequence shown in Figure 13 can be naturally explained. The Mgb index is substantially higher in early-type galaxies, which is interpreted as a result of a relatively shorter star formation timescale. Late-type galaxies, on the other hand, show markedly lower values of Mgb with a clear decreasing trend from S(B)a to S(B)d along the Hubble Sequence. This result is consistent with the general understanding of a longer star formation timescale in a later Hubble type. Comparing Figure 12 with Figure 13, we can see that the Mg line strength changes more dramatically with Hubble type than Fe5270 does.
As we mentioned in the previous two sections, all of the available information must be considered together in order to derive $\alpha/\text{Fe}$ based on the Mgb measurements.

4.4. Comparison with Stellar Population Models

In principle, Balmer lines and metal lines are affected by both age and metallicity at some level and, therefore, the question is whether we can find a good combination of line indexes with which the degeneracy spell can be broken. It was Worthey (1994) who did this first and numerous investigations followed this approach.

Figure 14 shows the average (median) properties of Hubble types in comparison to the simple stellar population model grids (Thomas et al. 2003). For our cursory inspection, we
took the models of [α/Fe] = 0.3 for simplicity. We adopted [MgFe]′ as a metallicity indicator from Thomas et al. (2003). This index is relatively less sensitive to [α/Fe], but still reflects the contribution of α elements to metallicity. It should be noted that, even in this Hβ–[MgFe]′ plane, which is supposed to be more successful than any other for breaking the age–metallicity degeneracy spell, the degeneracy was still visible. In other words, age and metallicity can have similar effects on the two indexes.

Roughly speaking, there was a general trend of decreasing age and metallicity from early- to late-type galaxies. Early-type galaxies were barely distinguishable in age or metallicity between subclasses and had median ages of roughly 8 Gyr and metallicities that were above solar. However, it is important to remember that the age and metallicity estimates were the luminosity-weighted values and, therefore, a “frosting effect” from a small fraction (say a few percent) of young stars could easily influence them (Trager et al. 2000a).

In comparison, the luminosity-weighted ages of the spiral galaxies were substantially smaller, between 2 and 5 Gyr. It should be noted that the SDSS spectra were sampled from the SDSS fiber that covered only the central 1:5 in radius. While the details depend on the apparent size and morphology type of the galaxy, this method basically sampled more lights from the central bulge and, therefore, may not represent the entire galaxy. This fact should be kept in mind when it is noted that the spiral bulges from this exercise appeared to be sub-solar in metallicity. However, this result was also subject to the frosting effect.

As mentioned in Section 4.3, [α/Fe] can be constrained by comparing observational data with simple stellar population models. Figures 15 and 16 show the 3 Gyr and 8 Gyr model grids for the late-type and early-type galaxies, respectively. The choice of the typical age for late- (3 Gyr) and early- (8 Gyr) type galaxies was roughly based on Figure 14. The Sa and SBa galaxies are shown in Figure 16 with the early-type galaxies because their characteristics in age and metallicity (within the SDSS fiber) were more comparable to those of early-type galaxies than to those of late-type galaxies.

The α-to-iron index, [α/Fe], was derived from the Mgb–(Fe) plane, where (Fe) was defined as (Fe5270+Fe5335)/2 by Gorgas et al. (1990). The late-type galaxies in Figure 15 were roughly consistent with [α/Fe] = 0.0, whereas the early-type galaxies in Figure 16 favored larger values between [α/Fe] = 0.0 and 0.3. Our results are consistent with those of previous studies (Worthey et al. 1992; Vazdekis et al. 1997; Trager et al. 2000b; Thomas et al. 2005; Schiavon 2007). This procedure was undoubtedly based on circular logic, as we first selected rough age estimates by pre-fixing the value of [α/Fe] (0.3) in Figure 14. In principle, we could overcome this circular argument by iterating this process on each Hubble type (instead of using a uniform value of [α/Fe] for all types). However, it would not be very meaningful to derive properties beyond what was already done in this study, because our aim was not to derive accurate values of ages and metallicities of galaxies. Instead, our aim was to demonstrate how to use our database in order to derive such properties in more detailed application studies in the future. In addition, such an iteration would require multiple steps of interpolations with model grids, which would generate numerical errors that would not be much smaller than the uncertainty we have in our current simple analysis.

Extreme late-type galaxies (Sd, Sbd) and irregular galaxies extend outside the grids in Figure 15. This result may indicate [α/Fe] < 0.0, but it may also be due to the small number statistics.

Figure 14. [MgFe]′ vs. Hβ absorption indexes with model grids from Thomas et al. (2003). The median values are shown here. The inset zooms in on the high [MgFe]′ and low Hβ regions. The standard deviation values are omitted for clarity, but can be seen in Tables 4 and 5.

Figure 15. Mgb vs. (Fe) for late-type galaxies with the 3 Gyr model grids of TMB03. Note that Sa and SBa galaxies are shown in Figure 16 with the early-type galaxies. See the text for details.

Figure 16. Same as Figure 15 but for Sa, SbA, and early-type galaxies. The models are for the age of 8 Gyr. See the text for details.
5. EMISSION-LINE STATISTICS

Nebular emission lines reveal the physical state of ionized gas and, therefore, are useful for studying nuclear activities around a central supermassive black hole and star formation. It is not trivial to distinguish one effect from the other, because both star-forming regions and active galactic nuclei (AGNs) can excite Balmer and forbidden lines. Baldwin et al. (1981, hereafter referred to as BPT) introduced several combinations of emission-line ratios that can be used to do just this (see also Kewley et al. 2001; Kauffmann et al. 2003). In comparison to star-forming regions, AGNs are assumed to produce photons with higher energy and, therefore, are more effective at producing extended partially ionized regions and inducing collisional excitations. These results lead to higher ratios of the collisionally excited forbidden lines over the photoionization-induced Balmer emission lines. The idea has been confirmed further by Veilleux & Osterbrock (1987) and now even finer classifications of the AGNs, such as Seyferts and low-ionization nuclear emission-line regions (LINERs), are often attempted (Heckman 1980; Kewley et al. 2006).

In Figure 17, we present a BPT diagnostic diagram of our galaxies with emission lines. We selected the emission-line galaxies using the cut \( A/N \geq 3 \), where \( A \) is the best-fitting amplitude of the emission line being considered and \( N \) is the level of noise in the residuals of the gandalf fit (see Oh et al. 2011 for details). This cut selected galaxies with statistically significant emission lines on all four lines that we considered in this diagnosis. Approximately 48% of our samples exhibited all four emission lines above this cut: 9% of the early-type galaxies and 59% of the late-type galaxies. However, it should be noted that this does not mean that 52% of our samples were non-emission galaxies. Many of the galaxies satisfied our \( A/N \) criterion only on two or three lines instead of all four.

In Figure 17, the size of each symbol indicates the black hole mass, while its color indicates the \((g-r)_0\) color of the galaxy. The black hole mass was derived based simply on velocity dispersion following Gültekin et al. (2009). The emission-line classification results are summarized in Table 1.

As expected, the late-type galaxies (right panel) were optically blue and most of them showed emission lines due to star formation. Their black hole masses were generally smaller than those of the early-type galaxies. Most early-type emission-line galaxies (left panel) were classified as LINERs. Among AGNs, LINERs in particular have a heavier black hole than Seyferts do. A similar trend of increasing black hole mass from left to right is visible in the early-type galaxies as well. The results of this study were consistent with the earlier findings of Schawinski et al. (2007). The sub-classifications are summarized in Figure 18. The galaxies with low or no emission lines (\( A/N \leq 1 \)) were categorized as “weak-emission galaxies” and those with \( 1 < A/N < 3 \) were classified as “unclear” and, therefore, they were excluded from this figure. For example, the numbers above the bar for \( E_{\text{cut}} \) indicate that there were 463 elliptical galaxies altogether that were either classified as “emission-line” or “weak-emission.” Of the 463 elliptical galaxies, 118 were “emission-line” galaxies. Since there were 1,359 elliptical galaxies altogether in Figure 1, then 896 (from 1359 – 463) of the elliptical galaxies were classified as “unclear.” Considering that the bulk of the galaxies were unclassifiable in terms of central activities, our statistics (fractions) should be used with caution.

Earlier-type galaxies consistently showed a higher AGN fraction. In addition, there was a clear tendency for an increasing fraction of star-forming galaxies within late-type galaxies along the Hubble Sequence. The extreme late-type galaxies, Sd, SBd, and Irr, were primarily star forming, as expected.

5.1. Accretion Rate

The forbidden emission line from doubly ionized oxygen, [OIII], is often used to estimate the black hole gas accretion rate (Kauffmann et al. 2003). The ionization near AGNs is caused by the central black hole and, therefore, a strong [OIII] emission indicates a high accretion rate by the black hole. In order to eliminate the effect of the black hole mass influencing the emission-line strengths, we divided the line strength from the OSSY catalog by \( \alpha \) (Heckman et al. 2004; Best et al. 2005;
Figure 18. Sub-classification in terms of emission line statistics. This figure shows the fractions of weak-emission, star-forming, composite, Seyfert AGN, and LINER host galaxies in each classification. There are two numbers above each bar. The first number indicates the number of “emission-line” galaxies that show all four emission lines with \( A/N \geq 3 \) confidence, and the second number indicates the number of “emission-line” galaxies plus “weak-emission” galaxies that have all four lines with \( A/N \leq 1 \). Unclear galaxies with \( 1 < A/N < 3 \) do not appear in this plot.

Table 1

| Classification        | \( N \) | Emission-line\(^a\) | \( \%(\text{Emission}) \) | \( \%(\text{Total}) \) | \( E_{\text{tot}} \) | S0    | Sa   | Sb   | Sc   | Sd   | SBA  | SBb  | SBc  | SBD  | Irr  |
|-----------------------|--------|----------------------|----------------------------|-------------------------|----------------------|--------|------|------|------|------|------|------|------|------|------|
| Emission-line galaxies\(^c\) | 3543   | 100                  | 3.33                       | 0.93                    | 2.96                 | 38.87  | 30.68| 2.09 | 1.72 | 11.01| 5.39 | 0.40 | 2.62 |
| Star-forming          | 2345   | 66                   | 0.51                       | 0.14                    | 0.62                 | 25.23  | 26.50| 2.09 | 0.56 | 4.15 | 3.56 | 0.40 | 2.43 |
| Transition region     | 775    | 22                   | 0.87                       | 0.28                    | 1.30                 | 9.68   | 3.25 | 0.00 | 0.51 | 4.40 | 1.38 | 0.00 | 0.20 |
| Seyfert               | 170    | 5                    | 0.25                       | 0.14                    | 0.28                 | 2.03   | 0.45 | 0.00 | 0.14 | 1.24 | 0.25 | 0.00 | 0.00 |
| LINER                 | 253    | 7                    | 1.69                       | 0.37                    | 0.76                 | 1.92   | 0.48 | 0.00 | 0.51 | 1.21 | 0.20 | 0.00 | 0.00 |
| Unclear\(^d\)         | 3447   | (46)                 | (0.81)                     | (0.17)                  | (0.36)               | (0.92) | (0.23)| (0.00)| (0.24)| (0.58)| (0.09)| (0.00)| (0.00)|
| Weak-emission\(^e\)   | 439    | (6)                  | (12.06)                    | (3.22)                  | (3.49)               | (10.23)| (10.30)| (0.63)| (1.59)| (3.30)| (1.28)| (0.05)| (0.26)|

Notes. The upper and lower rows for each morphology class indicate the percent of the “emission-line” galaxies and total sample, respectively.

\(^a\) Percent of “emission-line” galaxies (\( N = 3543 \)).

\(^b\) Percent of the total sample (\( N = 7429 \)).

\(^c\) \( A/N \geq 3 \) for \([\text{N} \text{II}] \) \( \lambda 6584 \), \( \text{H} \alpha \), \([\text{O} \text{III}] \) \( \lambda 5007 \) and \( \text{H} \beta \) emission lines.

\(^d\) \( 1 < A/N < 3 \).

\(^e\) \( A/N \leq 1 \).

Kewley et al. (2006), assuming that the \([\text{O} \text{III}]\) luminosity scales with the AGN bolometric luminosity and \( \sigma^4 \) traces the mass of the black hole (Ferrarese & Merritt 2000; Gebhardt et al. 2000). Figure 19 shows the characteristic values for Hubble classes. Elliptical galaxies have a larger black hole than late-type galaxies and, therefore, they have a stronger \([\text{O} \text{III}]\) emission line. However, when normalized by the proxy to the black hole mass, the elliptical galaxies do in fact show a lower value of accretion rate. This result is consistent with earlier works by Heckman et al. (2004) and Wu & Liu (2004). This result is perhaps due to the fact that elliptical galaxies have a less copious supply of gas for accretion.

An important caveat of using the SDSS data is that SDSS uses a 3′′ diameter fixed fiber. Sarzi et al. (2010) noted that
Figure 19. \(\text{[O} \text{iii}] / \sigma^4\) as a proxy to the black hole mass accretion rate for the AGN host galaxies. The number below each classification label indicates the number of galaxies in each bin.

Figure 20. \(H\alpha\) equivalent width of star-forming galaxies. The number below each classification label indicates the number of galaxies in each bin.
such a wide fiber will allow much of the diffuse stellar light to contaminate the lights from the black hole gas accretion. As a result, many of the LINER candidates based on the SDSS spectra may not be real AGNs.

5.2. Hα Emission Line

Hydrogen emission lines have been widely used as an indicator of star formation (Cohen 1976; Kennicutt & Kent 1983; Romanishin 1990; Gavazzi et al. 1991; Kennicutt 1998; Ryder & Dopita 1994; Gallego et al. 1995; Kennicutt 1998; Brinchmann et al. 2004; Salim et al. 2007). Young, hot stars produce H II regions first and then the ionized hydrogens undergo the recombination process, thereby resulting in the emission of line fluxes. We show in Figure 20 the Hα emission-line strength in equivalent width from the OSSY catalog, along the Hubble Sequence. We show only the non-AGN host galaxy candidates based on the BPT diagnostics. The emission-line strength normalized by the stellar mass (because it was given in equivalent width) was extremely low in early-type galaxies. There was a clear trend of increasing emission line strength along the Hubble Sequence among late-type galaxies.

6. DENSITY

In this section, we discuss whether or not there is any trend or peculiarity in the Hubble Sequence in terms of the local environment. By simply counting the galaxies that were within 25 arcsec (roughly 1 Mpc at the distance of our sample galaxies) of our target galaxy, we measured its projected density parameter. Both the target and neighboring galaxies were required to satisfy the same luminosity cut, $M_r \leq -18.65$. We chose this cylindrical approach over elaborate sphere or ellipsoid approaches, because it is difficult to consistently correct the peculiar motion effect along the line of sight through all of the density ranges, no matter which shape is chosen for the search volume. If our target galaxies were all inside clusters, then an ellipsoidal search would have been more effective (Yoon et al. 2008). However, our samples were heavily mixed in terms of the environment. We tried giving weights based on distance (Yoon et al. 2008), but it only caused a minor difference in our results. Therefore, we decided to simplify our density measurement so that its meaning (as a density measure) was clearer.

A density measurement would be inaccurate for the galaxies near the SDSS survey boundary, because their search cylinder cannot be complete. Therefore, we removed 185 (2.5%) such galaxies from our study samples. It should be noted that we only counted the galaxies with spectroscopic information and, therefore, our density parameter was subject to the spectroscopic completeness of the SDSS survey (Yoon et al. 2008). It should also be noted that we were counting all the galaxies above the brightness cut in the redshift range, whether they were morphologically classified or not, as we did not make any distinction in the morphology when counting the galaxies.

Figure 21 shows our results for density. The median of the density parameters was 5 for the entire sample. This result indicates that there were typically only 5 SDSS spectroscopic galaxies with $M_r \leq -18.65$ inside a search cylinder. Quite a few galaxies (823, 11%) had a density parameter greater than 20 and 42 of them even reached beyond 100. Visual inspection of their SDSS images indicated that they were likely associated with galaxy clusters. We did indeed identify the following 15
Table 2
Basic Properties of the Early-type and Lenticular Galaxies

|   | E0  | E1  | E2  | E3  | E4  | E5  | Etot | S0  |
|---|-----|-----|-----|-----|-----|-----|------|-----|
| Number | 63  | 342 | 412 | 322 | 181 | 39  | 1359 | 330 |
| \(C_r\)^b | 3.20 | 3.17 | 3.22 | 3.23 | 3.20 | 3.18 | 3.21 | 3.10 |
| \(\log(\text{g})\) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| \(M_r\) | -21.37 | -21.35 | -21.45 | -21.47 | -21.48 | -21.47 | -21.44 | -20.97 |
| \(\log(M_r/M_\odot)\) | 10.99 | 10.97 | 10.12 | 11.04 | 11.01 | 10.98 | 11.00 | 10.81 |
| Density | 9.00 | 7.00 | 8.00 | 9.00 | 7.00 | 8.00 | 8.00 | 7.00 |

Notes.
- a Number of galaxies for each morphology.
b Concentration index, \(C_r = \text{PetroR90}/\text{PetroR50}\). The rows from the top to bottom of each column represent the median \(\sigma\) distribution and mean values in parenthesis.
c \(\text{FracDeV}\), de Vaucouleurs fraction of the SDSS-\(r\) band.
d \(k\)-corrected \((g-r)_{0}\) color using the Petrosian magnitude.
e \(r\)-band absolute magnitude.
f Logarithmic scale of the stellar mass derived from the method developed by Bell et al. (2003).
g Number density. Number of galaxies within a cylinder with 1 Mpc radius and 0.033 < \(z\) < 0.044 height. Note that the faint galaxies were already eliminated by the volume-limitation process. The galaxies with no spectroscopic data were also not counted.

Table 3
Basic Properties of the Late-type and Irregular Galaxies

|   | Sa  | Sb  | Sc  | Sd  | SBa | SBb | SBe | SBd | Ir  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Number | 378 | 2144 | 1852 | 121 | 190 | 639 | 286 | 18  | 112 |
| \(C_r\) | 2.97 | 2.33 | 2.09 | 2.05 | 2.73 | 2.41 | 2.24 | 2.11 | 2.08 |
| \(\log(\text{g})\) | 0.95 | 0.24 | 0.14 | 0.14 | 0.92 | 0.73 | 0.41 | 0.44 | 0.20 |
| \(M_r\) | -21.19 | -20.83 | -20.39 | -19.46 | -21.11 | -21.25 | -21.07 | -19.48 | -20.00 |
| \(\log(M_r/M_\odot)\) | 10.89 | 10.57 | 10.28 | 9.83 | 10.86 | 10.81 | 10.66 | 9.96 | 9.98 |
| Density | 7.00 | 5.00 | 4.00 | 4.00 | 6.00 | 5.00 | 5.00 | 3.00 | 4.00 |

Notes.
- a Number of galaxies for each morphology.
b Concentration index, \(C_r = \text{PetroR90}/\text{PetroR50}\). The rows from the top to bottom of each column represent the median \(\sigma\) distribution and mean values in parenthesis.
c \(\text{FracDeV}\), de Vaucouleurs fraction of the SDSS-\(r\) band.
d \(k\)-corrected \((g-r)_{0}\) color using the Petrosian magnitude.
e \(r\)-band absolute magnitude.
f Logarithmic scale of the stellar mass derived from the method developed by Bell et al. (2003).
g Number density. Number of galaxies within a cylinder with 1 Mpc radius and 0.033 < \(z\) < 0.044 height. Note that the faint galaxies were already eliminated by the volume-limitation process. The galaxies with no spectroscopic data were also not counted.
## Table 4

Spectroscopic Properties of the Early-type and Lenticular Galaxies

|       | E0   | E1   | E2   | E3   | E4   | E5   | Eint | S0   |
|-------|------|------|------|------|------|------|------|------|
| Number| 63   | 342  | 412  | 322  | 181  | 39   | 1359 | 330  |
| \(\sigma_{\text{gif}}\) (km s\(^{-1}\)) | 155.7 | 164.1 | 176.7 | 186.9 | 177.1 | 168.8 | 175.4 | 155.0 |
| H\(\beta\) (Å) | 1.79 | 1.80 | 1.81 | 1.76 | 1.79 | 1.83 | 1.79 | 1.87 |
| Fe\(5270\) (Å) | 2.75 | 2.77 | 2.79 | 2.80 | 2.79 | 2.78 | 2.78 | 2.79 |
| [MgFe] \(\epsilon\) | 3.31 | 3.33 | 3.35 | 3.38 | 3.36 | 3.42 | 3.35 | 3.32 |
| Mgb (Å) | 4.07 | 4.12 | 4.12 | 4.19 | 4.17 | 4.18 | 4.15 | 4.01 |
| \(\log(M_{\text{BH}}/M_{\odot})\) (AGN) | 8.24 | 7.87 | 7.80 | 8.11 | 8.29 | 0.00 | 7.96 | 7.95 |
| \(\log(L_{[O\text{III}]}/\sigma_{\text{f}})^{1/2}\) | -2.44 | -2.28 | -2.20 | -2.34 | -2.42 | 0.00 | -2.42 | -2.18 |
| H\(\alpha\) (Å) | 0.50 | 0.45 | 0.42 | 0.53 | 0.52 | 0.24 | 0.47 | 0.58 |
| Notes. | \(\sigma_{\text{gif}}\): Effective velocity dispersion calculated from the formulae by Graham et al. (2005) and Cappellari et al. (2006).
H\(\beta\): Equivalent width provided by the OSSY catalog with the quality-assessing parameter, \(N_r < 2\) and EW > 0. The rest of the stellar absorption-line features follow the same criteria. Here, 97.7% of the sample galaxies were used by the selection cut. Fe\(5270\): Equivalent width. 96.8% of the sample galaxies were used. [MgFe] \(\epsilon\): Equivalent width. [MgFe] \(\epsilon = \sqrt{\text{Mgb}(0.72}\times \text{Fe}5270+0.28\times \text{Fe}5335)}\) (Thomas et al. 2003). 94.4% of sample galaxies are used. Mgb: Equivalent width. 97.2% of the sample galaxies were used. Central black hole mass of the AGN derived by Gültekin et al. (2009) using velocity dispersion. L/[OIII] for the AGN divided by the effective velocity dispersion to the power of four. Note that the indices for the several of the morphology classes (E0, E5, Sd, Sb, Sbc and Irr) were not reliable due to the sample size. The number of galaxies used to derive the index for each classification are shown in Figure 19. H\(\alpha\): Equivalent width for non-AGN galaxies. The number of galaxies for each classification are shown in Figure 20. |
Table 5
Spectroscopic Properties of the Late-type and Irregular Galaxies

| Sa  | Sb  | Sc  | Sd  | SBa | SBB | SBC | SBd | Irr |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Number | 378 | 2144 | 1852 | 121 | 190 | 639 | 286 | 18 | 112 |
| $\sigma_{\text{eff}}$ (km s$^{-1}$) | +37.50 | +43.54 | +28.12 | +29.97 | +37.07 | +38.49 | +38.92 | +5.89 | +68.97 |
| H$\beta$ | 1.98 | 2.76 | 2.91 | 3.33 | 1.92 | 2.46 | 2.72 | 3.09 | 3.73 |
| (Å) | 4.59 | 4.71 | 4.75 | 4.94 | 4.62 | 4.69 | 4.79 | 5.57 | 5.55 |
| Fe5270 | 2.71 | 2.13 | 1.90 | 1.45 | 2.74 | 2.40 | 2.16 | 1.49 | 1.11 |
| (Å) | 2.09 | 2.77 | 2.92 | 3.25 | 2.09 | 2.43 | 2.72 | 3.08 | 3.56 |
| [MgFe]$^*$ | 3.12 | 2.20 | 1.82 | 1.27 | 3.17 | 2.61 | 2.20 | 1.25 | 1.07 |
| (Å) | 3.01 | 4.06 | 4.61 | 4.60 | 4.32 | 4.62 | 4.76 | 4.64 | 4.58 |
| Mgb | 3.66 | 2.37 | 1.85 | 1.19 | 3.69 | 2.88 | 2.31 | 0.99 | 1.01 |
| (Å) | 3.04 | 2.21 | 1.85 | 1.37 | 3.03 | 2.56 | 2.18 | 1.32 | 1.16 |
| log($M_{\text{BH}}/M_{\odot}$) | 6.89 | 6.63 | 6.00 | 6.00 | 6.74 | 6.69 | 6.20 | 0.00 | 0.00 |
| (AGN) | 6.65 | 4.59 | 4.76 | 4.00 | 5.52 | 4.58 | 5.58 | 0.00 | 0.00 |
| 0.61 | 0.71 | 0.97 | 0.00 | 0.86 | 0.59 | 0.33 | 0.00 | 0.00 |
| (7.21) | (6.94) | (6.50) | (0.00) | (5.93) | (6.98) | (6.46) | (0.00) | (0.00) |
| log([$L/\text{O iii}$/σ$^+$]) | -1.09 | -0.90 | -0.61 | 0.00 | -1.31 | -0.79 | -0.46 | 0.00 | 0.00 |
| Hα | 1.24 | 1.10 | 1.32 | 0.00 | -0.81 | -0.19 | 0.67 | 0.81 | 0.00 |
| (Non-AGN)/(Å) | 4.55 | 4.69 | 4.75 | 4.00 | 4.91 | 1.59 | 0.47 | 1.40 | 0.00 |
| (-0.73) | (-0.76) | (-0.70) | (-0.49) | (-0.93) | (-0.92) | (-1.01) | (-0.23) | (-0.41) | (-0.41) |
| (5.11) | (15.64) | (17.88) | (27.83) | (5.47) | (16.42) | (21.34) | (38.81) | (53.79) |
Table 6
Morphology Catalog Including Spectroscopic and Photometric Properties

| SDSS ObjID | Morphologya | R.A. (deg)b | Decl. (deg)b | Redshift | g−r |
|------------|-------------|-------------|-------------|----------|-----|
| 587741708323193271 | 16 | 121.37498 | 12.369875 | 0.036951199 | 0.802 |
| 58772718007288271 | 22 | 28.01761 | −8.7224340 | 0.036953799 | 0.701 |
| 587726100416495842 | 22 | 229.10187 | 2.8465180 | 0.036954898 | 0.562 |
| 58774122176968466 | 12 | 134.52182 | 22.776091 | 0.036959500 | 0.824 |
| 58773002225785243 | 13 | 226.68094 | 5.3271850 | 0.036956899 | 0.909 |

M_{B} | IsoA_{e} (arcsec) | IsoB_{e} (arcsec) | C_{r} | fracDeV | log(M_{*}/M_{⊙}) |
|------|------------------|------------------|-------|----------|-----------------|
| −21.078 | 49.253 | 22.827 | 3.096 | 0.930 | 10.873 |
| −21.569 | 61.106 | 34.870 | 2.581 | 0.901 | 10.959 |
| −20.122 | 42.913 | 20.939 | 2.075 | 0.000 | 10.228 |
| −21.860 | 72.966 | 55.174 | 3.413 | 1.000 | 11.210 |
| −21.676 | 57.899 | 42.418 | 3.154 | 0.929 | 11.229 |

σ_{eff} (km s^{-1})^{c} | Hβ (Å) | Fe5270 (Å) | (Fe) (Å) | Mgb (Å) | [MgFe]^{e} (Å) |
|------------------|------------------|------------------|-------|-------|------------------|
| 173.860 | 1.623 | 2.674 | 2.713 | 4.368 | 3.432 |
| 100.353 | 3.181 | 1.806 | 1.894 | 1.879 | 1.867 |
| 23.595 | 2.655 | 1.728 | 1.555 | 1.558 | 1.594 |
| 222.164 | 1.685 | 2.934 | 2.814 | 4.431 | 3.564 |
| 234.506 | 1.653 | 2.741 | 2.623 | 4.773 | 3.573 |

BPT Classa | log(M_{HII}/M_{⊙})^{d} | He (Å) | log(L[O III]/σ)^{d} | N_{density} |
|------|------------------|-------|------------------|--------|
| 5 | 7.847 | 0.524 | −9999 | 6 |
| 3 | 6.575 | −9999 | 0.190 | 10 |
| 1 | 3.698 | 23.485 | −9999 | 16 |
| 0 | 8.277 | 0.195 | −9999 | 11 |
| 5 | 8.396 | 0.137 | −9999 | 18 |

Notes. The full catalog contains 10,233 objects.
a E0–E5: 10–15; S0: 16; Sa–Sd: 21–24; SBa–SBd: 31–34; Irr: 40; unknown: 50.
b 12000.
c “<9999” is assigned when the criteria (C_{r} < 3.5 & 10 < σ_{eff} < 400) [km s^{-1}] is not satisfied.
d 0: weak-emission (A/N < 1); 1: star-forming; 2: transition region; 3: Seyfert; 4: LINER; 5: unclear (1 < A/N < 3).
e “<9999” is assigned when σ_{eff} is “<9999.”
f “<9999” is assigned for AGN host galaxies.
g “<9999” is assigned for non-AGN galaxies or log(M_{HII}/M_{⊙}) is “<9999.”

(Supplemental data (FITS) for this table are available in the online journal. A portion is shown here for guidance regarding its form and content.)

early-type galaxies and 59% of the late-type galaxies were classified as “emission-line” galaxies.
11. The dominant process for the optical emission lines appeared to be AGN/LINER activity in early-type galaxies and star formation in late-type galaxies.
12. The late-type galaxies had higher accretion rates for gas by black holes than the early types did. This result was probably due to the fact that gas is more abundant in late-type galaxies.
13. The He emission-line strength, a proxy to the star formation rate, was much lower in early-type galaxies. This result is consistent with previous findings (Kennicutt & Kent 1983).
14. Early-type galaxies tended to reside in denser regions.

All of the indexes and parameters with regards to the galaxy morphology that are presented in this paper are summarized in Tables 2–5. We are pleased to release our morphology catalog including various spectroscopic and photometric properties (Table 6). It is our wish that this database will be useful as a reference.

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