COMPARING THE HOST GALAXIES OF TYPE Ia, TYPE II, AND TYPE Ibc SUPERNOVAE

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ABSTRACT

We compare the host galaxies of 902 supernovae (SNe), including SNe Ia, SNe II, and SNe Ibc, which are selected by cross-matching the Asiago Supernova Catalog with the Sloan Digital Sky Survey (SDSS) Data Release 7. We selected an additional 213 galaxies by requiring the light fraction of spectral observations to be >15%, which would represent well the global properties of the galaxies. Among these 213 galaxies, 135 appear on the Baldwin–Phillips–Terlevich diagram, which allows us to compare the hosts in terms of whether they are star-forming (SF) galaxies, active galactic nuclei (AGNs; including composites, LINERs, and Seyfert 2s) or absorption-line galaxies (Absorps; i.e., their related emission lines are weak or non-existent). The diagrams related to the parameters $D_n(4000)$, $H_\alpha$, stellar masses, star formation rates (SFRs), and specific SFRs for the SNe hosts show that almost all SNe II and most of the SNe Ibc occur in SF galaxies, which have a wide range of stellar masses and low $D_n(4000)$. The SNe Ia hosts as SF galaxies following similar trends. A significant fraction of SNe Ia occurs in AGNs and absorption-line galaxies, which are massive and have high $D_n(4000)$. The stellar population analysis from spectral synthesis fitting shows that the hosts of SNe II have a younger stellar population than hosts of SNe Ia. These results are compared with those of the 689 comparison galaxies where the SDSS fiber captures less than 15% of the total light. These comparison galaxies appear biased toward higher $12+\log(O/H)$ ($\sim 0.1$ dex) at a given stellar mass. Therefore, we believe the aperture effect should be kept in mind when the properties of the hosts for different types of SNe are discussed.

Key words: galaxies: abundances – galaxies: evolution – galaxies: formation – galaxies: spiral – galaxies: starburst – galaxies: star formation

Online-only material: color figures, machine-readable table

1. INTRODUCTION

Supernovae (SNe) are classified into various types (II, Ib, Ic, and Ia) according to the presence or absence of various features in their spectra (Filippenko 1997 and references therein). The presence or absence of hydrogen distinguishes Type II from Type I SNe. Among the Type I’s, the presence of Si lines characterizes Type Ib’s, while the presence of He lines distinguishes Type Ia’s, and the presence or absence of hydrogen distinguishes Type II from Type Ibc (Hamuy et al. 2002; Turatto 2003 and references therein).

SNe Ia are observed in all types of galaxies (ellipticals, irregulars, spirals), suggesting that they are somehow connected to the evolution of less-massive stars (e.g., Oemler & Tinsley 1979; van den Bergh 1990; della Valle & Livio 1994; Cappellaro et al. 1999). It is widely accepted that the progenitors of Ia SNe are carbon–oxygen white dwarfs (CO WDs), which have accreted material up to the Chandrasekhar limit (Chandrasekhar 1931) from non-degenerate companion stars in a single-degenerate (SD) model (Whelan & Iben 1973; Nomoto 1982), or come from a double-degenerate (DD) model, which involves the merger of two CO WDs (Iben & Tutukov 1984; Webbink 1984).

However, Type II, Ib, and Ic SNe are only found in star-forming (SF) galaxies, indicating that they are the product of the gravitational collapse of Fe cores during the evolution of massive stars. Thus, Type II and Type Ibc (which include Types Ib, Ic, and Ib/c) SNe are also called core-collapse SNe (CC-SNe). CC-SNe are thought to arise from stars with initial masses $>8 M_\odot$: this value results from the agreement between direct detections of progenitors (Smartt 2009) and the maximum observed mass for white dwarfs (WDs; Williams et al. 2009; Anderson & James 2009).

Many researchers have tried to understand how various types of SNe behave, including studying the masses of their progenitors, the effect of their environments, and the relations between the host properties and the SNe themselves, but generally these studies have only been based on small samples (Hamuy et al. 1995, 1996, 2000; Gallagher et al. 2005, 2008; Neill et al. 2009 for SNe Ia; Anderson & James 2009; Habergham et al. 2010 for CC-SNe).

The sample of studied SNe has been greatly extended in recent years, especially due to the successful projects associated with Sloan Digital Sky Survey (SDSS), both for galaxies (Strauss et al. 2002; Kauffmann et al. 2003a, 2003b; Brinchmann et al. 2004; Tremonti et al. 2004) and SNe (e.g., the SDSS-II Supernova Survey: Frieman et al. 2008; Zheng et al. 2008; Lampeitl et al. 2010; D’Andrea et al. 2010; Copper et al. 2009). The enlarged sample makes it possible to carefully compare the properties of the host galaxies of SN explosions. Some separate comparison studies have been made that examine the differences between galaxies that host SNe Ia and CC-SNe. Han et al. (2010)
investigated the color, luminosity, and environments of SNe Ia host galaxies in Stripe 82 of the SDSS-II Supernova Survey centered on the celestial equator. Kelly & Kirshner (2012) examined the host galaxies of core-collapse SNe where they separately inspected colors at the sites of the explosions, the chemical abundances, and specific star formation rates (SFRs) for hosts of SNe II, SNe IIn, SNe IIb, SNe Ib, and SNe Ic.

However, there are few works that combine the study of SNe Ia and CC-SNe to compare their hosts. Such studies are interesting and useful for understanding the environments where SNe explode, especially because some SNe Ia hosts are also SF galaxies like those for SNe II and SNe Ibc. Some researchers have performed such combined studies, but they have only focused on some limited aspects of the properties. For example, Prieto et al. (2008) mostly discussed the metallicities of galaxies and Hakobyan et al. (2012) mainly reported the creation of their database from SDSS-DR8 and presented some measurements from images. Therefore, many more comparisons are needed to study SNe host galaxies, such as studies that include the stellar populations, stellar masses, and SFRs, and so on. These properties are very important for understanding the characteristics of SN hosts.

In this work, we take into account SNe Ia, SNe II, and SNe Ibc (the latter two as CC-SNe) together to compare the properties of their hosts. In particular, we will use a stricter selection criterion to select the objects, for which the 3 arcsec fiber spectra of SDSS can represent the global properties of the galaxies better. We believe it is important to show the global properties of SN host galaxies since it is often difficult to acquire the local properties at the sites of an SN explosion.

Our idea can be summarized as follows. (1) We will compare the host galaxies of all kinds of SNe, including both Type Ia and CC-SNe (SNe II and Ibc). (2) We will compare them in terms of parameters that describe many properties, including stellar masses, SFRs, specific SFRs, $D_n(4000)$, H$_\delta_A$, and gas-phase oxygen abundances. (3) We also run spectral synthesis analysis on the optical spectra and obtain the light-weighted average ages for the host galaxies. (4) The hosts can be carefully checked following the classification from their high quality emission-line ratios, which can diagnose the hosts on the Baldwin–Phillips–Terlevich (BPT) diagram (Baldwin et al. 1981). Then SF galaxies, active galactic nuclei (AGNs), and absorption-line galaxies acting as hosts can be compared in terms of these property relations. (5) Since the sample is large, it is possible for us to manage a good sub-sample that can represent the global properties of the host galaxies, for which the 3 arcsec SDSS fiber observations can cover $>15\%$ light. This minimizes the cases where the fiber only records a small part of the global light of the hosts. (6) Then we can also carefully discuss the aperture effect of the SDSS fiber observations by comparing the two sub-samples (the ones that have a light fraction $>15\%$ and the others that have light fraction $\leq 15\%$); this approach gives clearer results for stellar mass–metallicity relations. (7) The properties of SNe hosts mentioned above will also be compared with the main sample of galaxies from SDSS-DR7.

This paper is organized as follows. We describe the sample selection in Section 2, which demonstrates how we select the 213 sample galaxies with a light fraction higher than 15% from the SDSS fiber observations, and the selection for the comparison sample galaxies is also mentioned. The parameters describing properties and their relations are shown in Section 3 for these hosts. Results of the stellar population analysis are presented in Section 4. Discussions are presented in Section 5, where we show the results of comparisons with the 689 comparison sample galaxies, the stellar mass–metallicity relation, and the aperture effect/bias. Conclusions are given in Section 6. Throughout the paper, a cosmological model with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$ and $\Omega_{\Lambda} = 0.7$ is adopted.

## 2. SAMPLE SELECTION

We select the SNe and their host galaxies by cross-matching the Asiago Supernova Catalog (ASC) with the SDSS DR7 main galaxy sample (MGS), only retaining spectral observations of the SNe host galaxies with good quality.

### 2.1. The Asiago Supernova Catalog (ASC)

The ASC was first published in 1984 by Barbon et al. (Barbon et al. 1984), who assembled all the pertinent information on the 568 SNe discovered from 1885 up to 1983, as well as some parameters associated with their host galaxies. The catalog was subsequently updated for newly discovered SNe. Barbon et al. (1989, 1999) and their group made the subsequent updates. Up through the end of 2013, the ASC includes 6312 SNe up to SNe 2013hx (http://graspa.oapd.inaf.it).

In this work, we adopted the R.A. and decl. of the SNe host galaxies in the ASC table, to enable cross-matching with the SDSS-DR7 MGS galaxies.

### 2.2. The SDSS Main Galaxy Sample Catalog (MGS)

The SDSS is the most ambitious astronomical survey ever undertaken in imaging and spectroscopy (York et al. 2000; Stoughton et al. 2002; Abazajian et al. 2003, 2004). The imaging data are done in drift scan mode and are 95% complete for the surveyed area for point sources at 22.0, 22.2, 22.2, 21.3, and 20.5 in five bands ($u, g, r, i,$ and $z$), respectively. The spectra are flux- and wavelength-calibrated from 3800 to 9200 $\AA$ at $R \approx 1800$.

The sample used in this work is selected from the SDSS-DR7 MGS (Strauss et al. 2002), which comprises galaxies with $r$-band Petrosian magnitude $14.5 < r < 17.77$ (corrected for foreground Galactic extinction using the reddening maps of Schlegel et al. 1998) and $r$-band Petrosian half-light surface brightness $\mu_{r, s} < 24.5$ mag arcsec$^{-2}$.

The parameters of the galaxies in SDSS-DR7 have been derived and published by the MPA/JHU group. We adopt their emission-line measurements and some properties of the galaxies, such as $D_n(4000)$, H$_\delta_A$, stellar masses, SFRs, and metallicities for the present work.

### 2.3. Cross-correlations of ASC and SDSS-MGS

To select the working sample of SNe host galaxies, we cross-correlated the coordinates of SNe host galaxies from ASC and the coordinates of spectral observations of the SDSS galaxies in their MGS with the following criteria.

1. Selecting those with well-defined SNe types. We first select the SNe and their host galaxies from the updated ASC (up to SN 2013Y; 6105 samples in total). Then only those having well-defined types of SNe, e.g., Type Ia, II, and Ib/c, are further selected; this is 4934 samples. It is worth noting here that the ASC contains events since 1885, and that a precise sub-classification, particularly of Type I’s, did not exist at the beginning of research about SNe.

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7 http://www.mpa-garching.mpg.de/SDSS/
2. First cross-matching with 30′′ radius. In the ASC, we note that the coordinates of the SNe host galaxies are not accurate enough in both R.A. (h:m:s) and decl. (d:m:s) since both terms of “s” are only due to integers without decimals. This could cause obvious discrepancy when matching the two catalogs, which may be up to 15 arcsec for R.A. (if the discrepancy up to ±1s) and a bit less for decl.

To minimize this problem, we adopt two steps for matching coordinates to select the final working sample. In the first, we adopt 30 arcsec as the matching radius to cross-correlate the coordinates of the 4934 SNe host galaxies in ASC with the SDSS DR7 MGS (698, 260 entries). This radius is large enough to consider the low precision of both R.A. and decl. This value is half the radius for matching used by Prieto et al. (2008). With this process, 1105 host galaxies are selected; by removing the duplicated and multiple spectral observations, 1041 host galaxies are retained.

3. Coordinate corrections. In order to improve the reliability of cross-matching between ASC and SDSS, we try to improve the accuracy of the coordinates of the SNe hosts in ASC. To do so, we retrieve the International Celestial Reference System (ICRS) coordinates (epoch in J2000) from SIMBAD (http://simbad.u-strasbg.fr) for the hosts by searching them by designation. The ICRS coordinates have two or three decimals for the “s” terms in R.A. and decl., which could improve the accuracy of matching between ASC and SDSS catalogs for SNe host galaxies. Out of 1041 host galaxies, we obtained the ICRS coordinates of 687 from SIMBAD, but the other 354 could not be found there, so we had to keep their original coordinates from ASC.

To show the necessity and significance of the improvement in such coordinate precision for the SNe host galaxies, in Figure 1 we plot the difference between the coordinates of the 687 SNe host galaxies from the ASC and those from the ICRS from SIMBAD which have the ICRS coordinates.

Figure 1. Discrepancy between the original coordinates of the 687 SNe host galaxies from the ASC and those from the ICRS from SIMBAD which have the ICRS coordinates.

4. Second cross-matching with 15′′ radius. We prefer a smaller radius for matching the two catalogs since it will help to avoid the mis-matching cases. Therefore, we adopt 15 arcsec as the matching radius to redo the cross-correlation for the 1041 SNe host galaxies from ASC and SDSS-DR7 MGS. Among them, 687 objects had revised R.A.–decl. as ICRS coordinates from SIMBAD as mentioned above. After this step, 980 objects were obtained (where 672 are from the 687 sample and 308 are from the 354 sample).

It is hoped that the 15 arcsec matching radius here can help to select as many interesting objects as possible and avoid the mistaken cases of cross-matching.

2.4. Light Fraction Criterion for Global Properties from Fiber Spectral Observations

The aperture of the fiber is 3 arcsec in the SDSS observations. In this study, we focus primarily on the global properties of the host galaxies taken from SDSS spectra. Thus, we select sample galaxies for which more than 15% of their light is covered by the fiber observations. This light fraction criterion (>15%) could help us to select the cases in which the 3 arcsec fiber observations of SDSS cover most of the light of the whole galaxy and thus retrieve the global properties of the SNe host galaxies.

One simple and accurate way to judge whether the fiber observations cover most of the light of the galaxies or not is to compare the fiber and Petrosian magnitudes of the SDSS galaxies. The fiber mag is a measurement of the light going down the fiber and the Petrosian mag is a good estimate of the total magnitude. Thus, we adopt the formula below to estimate how much light was covered by the fiber observations in the r band (Liang et al. 2010):

$$light\_fraction = 10^{-0.4(fiber\_mag - petro\_mag)}.$$  (1)

Figure 2 shows the relations between the calculated light fractions and the Petrosian radius in the r band for the selected 980 SNe hosts.

From Figure 2 we can see that for a large part of the SNe hosts, the 3 arcsec fiber of SDSS cannot cover more than 10% of the light from the whole galaxy. Here a slightly stricter criterion is used to select our sample galaxies, which have a light fraction larger than 0.15 in the spectral observations. To choose 0.15 of the light fraction here, we expect that a reasonable
sample of galaxies are selected for studies, of which the SDSS spectra could represent the properties of the whole galaxies, and we also expect that we will not lose too many larger-sized objects. Although we lose a large fraction of the initial sample by performing such a light fraction cut, we believe this cut is necessary to guarantee that the spectral observations are able to represent the global light of the galaxies rather than a small region inside the galaxy. We will discuss the effects of the lower light fraction cut. Above the 0.15 line, there are 243 objects. It is clear that galaxies with a light fraction lower than 0.15 will be used for comparison, and then the aperture effect will be shown clearly. After this step of removing misidentifications, 229 hosts are left.

2.5. Further Criteria

We perform further careful checks for the selected sample galaxies.

1. **Image checking by eye.** In order to guarantee the correction for host-identification between SNe and galaxies with SDSS observations, we check the 243 samples case by case and remove 14 cases that have misidentifications, e.g., cases where a SN explosion is located in a faint galaxy whose spectrum was not taken by SDSS observations but SDSS instead observed the spectra of bright galaxies quite close to it. After this step of removing misidentifications, 229 hosts are left.

2. **Spectral observations and quality control.** We downloaded the SDSS one-dimensional spectra of these 229 SNe host galaxies. Some of them have to be removed since interruptions appear in their spectral energy distributions (SEDs). After this cleaning, we have 213 SNe host galaxies left whose signal-to-noise ratios (S/Ns; median value per pixel of the whole spectrum provided in the MPA/JHU catalog) are larger than 5.

3. **Three sub-samples associated with emission-line ratios.** Since we are working on the properties of host galaxies of SNe, it will be interesting to check their emission or absorption lines. In the total sample of 213 SNe host galaxies, 135 have good quality observations in all four emission lines ([NII]6583, Hα, [OIII]5007, and Hβ) with an S/N better than 3σ. They can be plotted on the BPT diagram (Baldwin et al. 1981) as shown in Figure 4. The remaining 78 objects either have a lower S/N in these four emission lines or only display some or none of the lines. Thus, the sample galaxies can be divided into three sub-samples:

   1. 82 SF galaxies identified by their emission-line ratios on the BPT diagram,
   2. 53 AGNs (including composites, LINERs, and Seyfert 2s), and
   3. 78 absorption-line and weak emission-line galaxies (called simply “absorption” galaxies; hereafter Absorps) that do not appear on the BPT diagram due to the absence of some or all of the four emission lines mentioned above.

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**Table 1**

Basic Information for the Sample Galaxies, Including All Types of SNe

| No. | R.A. (ASC) | Decl. (ASC) | R.A. (SDSS) | Decl. (SDSS) | PID-MJD-FID | Petron Radius | Light Fraction | Redshift | Type | Name of SN |
|-----|------------|-------------|-------------|-------------|-------------|---------------|---------------|----------|------|-----------|
| 111 | 105741     | 573648      | 164.42208862 | 57.61346436 | 0949-52427-109 | 6.375 | 0.193 | 0.080 | Ia  | 2010 bg   |
| 99  | 230548     | 141956      | 346.45358276 | 14.33142471 | 0742-52263-590 | 7.429 | 0.209 | 0.108 | Ia  | 2012 ff   |
| 153 | 131523     | 462509      | 198.84954834 | 46.42004253 | 1461-53062-166 | 8.732 | 0.162 | 0.056 | II  | 2009 ct   |
| 130 | 163214     | 383920      | 248.05726624 | 38.65555954 | 1173-52790-537 | 8.355 | 0.150 | 0.039 | II  | 2012 ct   |
| 183 | 112229     | 312305      | 168.12567139 | 31.38496208 | 2092-53460-516 | 6.309 | 0.176 | 0.027 | Ib  | 2011 bp   |
| 159 | 122450     | 082557      | 186.2083828 | 8.4370342    | 1626-53472-419 | 7.143 | 0.174 | 0.090 | Ic  | 2009 bh   |

**Notes.** The coordinates of host galaxies in the ASC (in hhmmss for R.A. and ddmmss for decl.) and SDSS-MGS (in degrees) are given. PID-MJD-FID are the three IDs used to take the SDSS spectra. The revised R.A. and decl. for some samples are given if we have them.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
In Section 3 we will plot the relations of some parameters associated with properties of the hosts of different types of SNe by marking their hosts as SF, AGN, or Absorp.

Table 2 shows the numbers of the hosts of the different types of SNe according to the galaxies appearing or not appearing on the BPT diagram as well as the total numbers of each type of SNe. We can see that among 169 SNe Ia hosts, 49 are SF galaxies, 49 are AGNs, and 71 are Absorp galaxies.

### 2.6. The Comparison Sample with a Low Light Fraction

For those galaxies whose light fraction is lower than 15%, we take them as a comparison sample and perform a similar analysis. Applying the light fraction cut and further selection criteria described in Section 2.5, this comparison sample includes 689 galaxies. All details about these galaxies will be given in Section 5.1, where we will show the difference between the 213 galaxy sample and 689 galaxy sample.

### 3. RELATIONS OF SOME PARAMETERS OF PROPERTIES FOR THE 213 SUPERNOVA HOST GALAXIES

Some parameters associated with properties can indicate the evolutionary status and SF history of galaxies. In this section, we plot some relations between properties of the 213 hosts for different types of SNe as shown in Figure 5. The parameters describing sample galaxies are taken from the MPA/JHU database.

\( \Delta A(4000) \). The break at 4000 Å is a strong interruption in the optical spectrum. Two narrow continuum bands (3850–3950 and 4000–4100 Å, narrower than the first definition by Bruzual 1983), as introduced by Balogh et al. (1999), were used to estimate this parameter. With increasing ages of the stellar populations of galaxies, the \( \Delta A(4000) \) values are increasing as well, indicating a larger fraction of older populations.

\( H_\alpha \delta \). A strong \( H_\alpha \) absorption line arises in galaxies that experienced a burst of star formation that ended about 0.1–1 Gyr ago. The peak of \( H_\alpha \) absorption occurs once hot O and B stars, which have weak intrinsic absorption, have terminated their evolution. The optical light from the galaxies is then dominated by late-B to early-F stars. Worthey & Ottaviani (1997) defined an \( H_\alpha \delta \) index using a central bandpass (4083–4122 Å) in the MPA/JHU database bracketed by two pseudo-continuum bandpasses.

The stellar masses of the SNe host galaxies are taken from Kauffmann et al. (2003b) and Gallazzi et al. (2005). Their SFRs are taken from Brinchmann et al. (2004; for the AGNs and absorption-line galaxies, they used the measured \( D_n(4000) \) value to estimate the SFRs and denote this as SFR\(_{d} \)).

Figure 5 presents some relations between properties of the SNe hosts. The \( D_n(4000) \) versus \( H_\alpha \delta \), stellar mass versus \( D_n(4000) \), stellar mass versus SFRs and stellar mass versus \( s \)SFRs are given from the first to fourth lines, respectively. On each line, the four panels show the relations when their hosts are SFs, AGNs, (composites, LINERs, and Seyfert 2s), and Absorps (absorption-line and weak emission-line galaxies), and then all 213 samples together with the SDSS MGS galaxies for background, respectively.

The results are as follows. First, since the sample of our galaxies is large and they have good-quality spectral observations, the host galaxies of SNe of different types can be discussed following their BPT diagrams. Then we can check whether their hosts are SFs, AGNs, or Absorps. Some of the previous studies often focus on one kind of host. For example, Prieto et al. (2008) only studied SF hosts with metallicities of 12+log(O/H) estimated from emission lines. Second, since we are considering hosts of SNe Ia, SNe II, and SNe Ibc together, we can compare the properties of hosts with different types of SNe, not just SNe Ia hosts or CC-SNe hosts.

From both Table 2 and Figure 5, we note that almost all the hosts of SNe II (the red triangles) are SF galaxies and most of the SNe Ibc also occur in SF galaxies. A significant part of the SNe Ia (the black filled circles) occur in AGNs and the absorption- (and weak emission-) line galaxies. The rest of the SNe Ia occur in SF galaxies, which means their hosts have young stellar populations. These findings are consistent with the observation that SNe Ia can occur in all kinds of galaxies, from SF to passive cases.

Since our sample of host galaxies with different types of SNe can be classified as SFs, AGNs, and Absorps, we can show the distributions of some parameters of the galaxies in these sub-groups. The top panels of Figure 5 show that the SF host galaxies with different types of SNe have various properties.
galaxies lie in the top left region of the sample, indicating that they have experienced very recent SF activities and their young populations (with $D_n(4000) < 1.4$) are dominate. The AGNs (composites, LINERs, and Seyfert 2s) and absorption-line galaxies occupy the region with lower H$_\delta_A$ and higher $D_n(4000)$, indicating they are dominated by old stellar populations. They are much more massive than the SF galaxies, which generally have log $M/M_\odot > 10$, while many of the SF hosts have both low (some down to log $M/M_\odot \sim 8$) and high (10 < log $M/M_\odot < 11$) stellar masses.

For all types of SNe (SNe Ia, SNe II, and SNe Ibc) hosts as SFs, they all span a wide range of mass ($8 < \log M/M_\odot < 11$) and there are no obvious differences among them. The relations of stellar mass and SFRs show the increasing SFRs following increasing stellar masses in a wide range of mass of log $M/M_\odot \sim 8$–11 for hosts of all types of SNe. In the bottom panels, the effect of mass was extracted from the SFRs where we put the sample galaxies in the relations of sSFRs versus stellar mass. The discrepancy between the different SNe hosts is clear: most SNe II hosts are SF galaxies; very few are AGNs or weak emission-line galaxies. SNe Ia can explode in all kinds of galaxies. The AGNs and absorption hosts show an obvious discrepancy from the SF hosts: they are more massive and have low sSFRs.

Figure 5. Relations among several property parameters for the 213 SNe host galaxies: the $D_n(4000)$ vs. H$_\delta_A$ and the stellar mass vs. $D_n(4000)$, and stellar mass vs. SFR and sSFR are shown on each line, respectively. The star-forming (SF) galaxies, AGNs (composite, LINER, and Seyfert 2s), absorption- and weak emission-line (Absorp(+WE)) galaxies, and the complete sample of all galaxies (Total) are shown in the panels from left to right. In all panels, the red triangles refer to the hosts of SNe II, the blue stars indicate the hosts of SNe Ibc, and the black filled circles denote the hosts of SNe Ia. These SNe host galaxies are compared with the SDSS main galaxy sample of galaxies (the dotted background) in the last panel of each line.

(A color version of this figure is available in the online journal.)
It is interesting to compare the SNe host galaxies with the global SDSS MGS galaxies. The last column on each line in Figure 5 shows that the SNe host galaxies fall well within the regions of SDSS main galaxies. From this column, we see the discrepancy between the SNe II hosts and the SNe Ia hosts. The SNe Ia can explode from SF to passive galaxies since their hosts fall within all the regions. Most of SNe II hosts are located in the regions of young spiral galaxies, suggesting they are dominated by young stellar populations. To summarize, the host galaxies of SNe preferentially occupy some sub-regions of the diagrams depending on their host properties and SNe types.

Here we also note that there are four SNe II hosts appearing in the figures that show Absorp galaxies. We further check the images and spectra of these hosts. We find that three of them (IDs 1461-53062-166, 0377-52145-289, and 0387-51791-587) are the so-called weak emission-line galaxies. Their H$\beta$ and/or [O III]5007 fluxes are under 3$\sigma$, while H$\alpha$ and [N II]6583 can be measured from their spectra. By using the upper limits of the line fluxes, we roughly estimate their positions on the BPT diagram. The results show that they should belong to star-forming galaxies, but close to the lower end of [O III]5007/H$\beta$, suggesting they may be metal-rich galaxies. Their [O III]5007 lines become too weak since there are many metal ions acting as coolants in metal-rich environments. There is one SN II host (ID 2586-54169-158) whose spectrum shows that it is a typical passive galaxy, but when we check its image, we find that there is a spiral galaxy very close to this SN II host. We think there may be some uncertainties when determining which galaxy is the host of this Type II SN, but this is beyond the research of this paper. There are still three SNe Ibc hosts appearing in Absorp galaxies and their situations are very similar to the four SNe II hosts. Two of them (IDs 0391-51782-442 and 1626-53472-419) are weak emission-line galaxies. The other SN Ibc host (ID 1337-52767-086) should be a passive galaxy according to both its image and its spectrum. This is interesting and should be studied further in future papers.

4. STELLAR POPULATIONS OF THE 213 HOST GALAXIES FROM SPECTRAL SYNTHESIS ANALYSIS

To retrieve the stellar populations of SNe hosts, here we consider all 213 sample galaxies as a representative sample for studying and comparing the properties of the hosts, i.e., the Type Ia, Type II, and Type Ibc SNe. Table 2 shows the corresponding numbers of host galaxies as 169, 34, and 10, respectively. Here we will obtain information about their detailed stellar populations by fitting the full optical spectra using the spectral synthesis method on both the continuum and absorption lines.

4.1. Spectral Synthesis Method

Spectral synthesis provides an efficient way to retrieve information about stellar populations of galaxies from observed spectra, which is a crucial step for a deeper understanding of galaxy formation and evolution. This is because galaxy spectra contain information on both the age and the metallicity distributions of their stars, which in turn reflects the star formation and chemical histories of the galaxies.

We fit the spectral absorption lines and continua of the sample galaxies to study their stellar populations by using the software Starlight8 (Cid Fernandes et al. 2005, 2007; Mateus et al. 2006; Asari et al. 2007; Chen et al. 2009). This software fits an observed spectrum $O_t$ with a model $M_t$ that adds up $N_t$ Simple Stellar Populations (SSPs) with different ages and metallicities from different stellar population synthesis models. A Gaussian distribution centered at velocity $v_o$ and broadened by $\sigma$, models the line-of-sight stellar motions. The fit is carried out with the Metropolis scheme (Cid Fernandes et al. 2001), which searches for the minimum $\chi^2 = \sum [(O_t - M_t) \omega_t^{-1}]^2$, where $\omega_t^{-1}$ is the error in $O_t$ except for masked regions. Pixels that are more than $3\sigma$ away from the rms $O_t - M_t$ are given zero weight by the parameter “clip.”

In the outputs of STARLIGHT, one of the most important parameters that traces the stellar population is the population vector $x$. The component $x_t(j = 1, \ldots, N_t)$ represents the fractional contribution of the SSP with age $t_j$ and metallicity $Z_j$ to the model flux at the normalization wavelength $\lambda_0 = 4020$ Å. Another important parameter, the mass fraction $\mu_j$, has a similar meaning. For the uncertainties in the fitting results, the Starlight group has carefully checked the reliability of this software by analyzing the stellar populations of fake galaxies made with known SSPs (see Figure 4 in Cid Fernandes et al. 2005 and Figure 1 in Cid Fernandes et al. 2004). Cid Fernandes et al. (2005) presented their error bars centered on the mean values obtained by fitting 20 realizations of each of 65 test galaxies. Their three condensed populations are recovered well by Starlight, with uncertainties smaller than 0.05 (young: $t < 10^9$), 0.1 (intermediate: $10^9 < t < 10^9$), and 0.1 (old: $t > 10^9$) for $S/N > 10$.

In this work, the optical spectra of the SNe host galaxies were fit by using the Starlight code. We use 45 SSPs from Bruzual & Charlot (2003, BC03), including 15 different ages from 1 Myr to 13 Gyr (i.e., 1, 3, 5, 10, 25, 40, 100, 280, 640, 900 Myr and 1.4, 2.5, 5, 11, 13 Gyr and 3 metallicities (i.e., 0.2, 1, and 2.5 $Z_\odot$); the stellar evolutionary tracks of Padova 1994 (Alongi et al. 1993; Girardi et al. 1996); the initial mass function of Chabrier (2003); and the extinction law of Cardelli et al. (1989) with $R_V = 3.1$. The Galactic extinctions are corrected with the reddening map of Schlegel et al. (1998), then shifted to the rest frame. The range of the spectra is from 3700 to 7800 Å with a step of 1 Å and normalized to the median flux in the 4010 to 4060 Å region. During spectral synthesis fitting, we exclude the emission lines, the sky lines, and four windows (5870–5905 Å, 6845–6945 Å, 7550–7725 Å, 7165–7210 Å), as done in Chen et al. (2009, 2010). For LINERs and Seyfert 2s, a power-law contribution has been added following Chen et al. (2010).

The Starlight code will result in a contribution to the percentage of each SSP at a given age and metallicity for the whole SED of the galaxy. To see the general trend, the SSPs are put in three bins: young populations with ages < 0.2 Gyr, intermediate populations with ages 0.2–2 Gyr, and old populations with ages > 2 Gyr (following Chen et al. 2010). The stellar populations at three metallicities (i.e., 0.2, 1, and 2.5 $Z_\odot$) are also obtained.

4.2. The Results from Starlight

We have done the spectral synthesis analysis for all 213 individual galaxies. In Figure 6, we show an example of the fitting and results.

This figure consists of four parts of plots: the top left one displays the synthesis spectrum (red line), the observed spectrum (black line), and the error spectrum (blue line); the bottom left one shows the residual spectrum where the green lines represent masked regions as given by the SDSS flag; the
right panel shows the fractional contribution in light (top) and mass (bottom) from the 45 SSPs with different ages. We list the resulting six parameters in the top right corners, namely $\chi^2$, the reduced $\chi^2$, the mean relative difference between synthesis and observed spectra $\Delta_{\lambda}$, the S/N in the region of 4730–4780 Å, the V-band extinction, the velocity $v_\star$, and the velocity dispersion $\sigma_\star$.

In Figure 7, we compare the stellar populations of hosts of different types of SNe, where we separate the 213 sample galaxies into three groups: hosts of SNe Ia, SNe II, and SNe Ibc, respectively. The top panel of Figure 7 presents the K-S test for the young populations ($<0.2$ Gyr) of the hosts of the three types of SNe. The middle panel of Figure 7 presents the K-S test for the metal-rich populations ($Z \sim 2.5 Z_\odot$) of the hosts of the three types of SNe, and the bottom panel shows the light-weighted mean ages ($\log t_\star L$) of the hosts of the three types of SNe.

The top panel of Figure 7 shows that the hosts of SNe II have more young stellar populations than hosts of SNe Ia. It is difficult for us to distinguish the hosts of SNe Ibc from the hosts of both SNe II and SNe Ia, partly owing to the small number of SNe Ibc hosts. The possibilities of two hosts being drawn from the same distribution are $3.8 \times 10^{-5}$ (Ia–II), 0.17 (Ia–Ibc), and 0.42 (II–Ibc). We should also note that there is still a fraction of SNe Ia hosts that have large young stellar populations, suggesting that SNe Ia can also explode in SF galaxies. The middle panel shows that the hosts of SNe Ia have more metal-rich stellar populations than hosts of SNe II. The differences between hosts of SNe Ibc and hosts of SNe Ia, as well as SNe II, are still not obvious. The possibilities of two hosts being drawn from the same distribution are $1.2 \times 10^{-4}$ (Ia–II), 0.56 (Ia–Ibc), and 0.15 (II–Ibc). The bottom panel shows that the hosts of SNe Ia have older ages than hosts of SNe II. Hosts of SNe Ibc are not distinguished from them obviously. For these 689 hosts from the comparison sample, we only show two sets of plots in Figure 8, following Figure 5 for the main working sample. As a result of the aperture effect, when we compare Figure 8 with Figure 5, we can see some low SFR cases at a given stellar mass are added in the 689 galaxies, which makes the data more scattered. Owing to adding some large spiral galaxies, whose central regions are just covered by SDSS, the SFRs of the 689 sample are lower than those of 213 samples. This phenomenon can be observed when we compare the 689 galaxy sample with the SDSS main galaxies in the fourth column of Figure 8, and compare this with the 213 galaxies in Figure 5. The aperture effects are shown then.

Therefore, we believe the criterion of a light fraction $>0.15$ is necessary to present the global properties of host galaxies of SNe.

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Therefore, we believe the criterion of a light fraction $>0.15$ is necessary to better present the global properties of host galaxies of SNe.

### Table 3

The Numbers of Different Types of SNe among the Galaxies Appearing or Not Appearing in the BPT Diagram and Total Number of Each Type for the 689 Galaxies

| Samples | Galaxies | Total | SN Ia | SN II | SN Ibc |
|---------|----------|-------|-------|-------|--------|
| SF      | Star-forming | 345   | 114   | 177   | 54     |
| AGN     | Composite | 155   | 66    | 54    | 15     |
| LINER   | 121      | 68    | 46    | 7     |
| Seyfert | 25       | 11    | 12    | 2     |
| Absorp  | Absorp. and WE | 63    | 40    | 19    | 4      |
| Total   | 689      | 299   | 308   | 82    |

**Note.** The meanings are the same as in Figure 5.
Figure 7. Cumulative fraction from the K-S test for the stellar populations of the three types of supernovae in the 213 sample galaxies: (a) for the young population (<0.2 Gyr), (b) for the metal-rich population (Z ∼ 2.5 Z⊙), (c) for the light-weighted mean ages ⟨logt∗⟩L of the three types of supernovae. The dot–dashed line is for hosts of SNe Ia, the solid line is for hosts of SNe II, and the dashed line is for hosts of SNe Ibc. (A color version of this figure is available in the online journal.)

Figure 8. Relations of stellar masses vs. SFRs and sSFRs for the 689 galaxy comparison sample. The symbols are the same as in Figure 5. (A color version of this figure is available in the online journal.)
5.2. The Gas-phase Metallicities and the Aperture Effect/Bias

The metallicities and stellar masses are fundamental parameters to indicate the evolution status and history of galaxies. Therefore, it is worth obtaining the relation of stellar mass versus metallicity (MZR) for the SNe host galaxies. This analysis is performed for both the 213 galaxies and the 689 comparison galaxies. Here, gas-phase oxygen abundances are taken into account, thus, only SF galaxies are considered. There are 74 from the 213 galaxy sample and 314 from the 689 comparison sample. Figure 9 shows that the 74 galaxies located closer to the MGS galaxies, but the 314 objects show about 0.1 dex higher $12+\log(O/H)$ at a given stellar mass. The details are given as follows.

The top panels of Figure 9 show the MZRs of 74 SF galaxies (among 213 samples) and the K-S test of the cumulative fraction of $12+\log(O/H)$ for hosts of SNe Ia, II, and Ibc. The hosts of SNe Ia are generally more metal-rich than the hosts of SNe II (Figures 9(a)–(c)). The lower panels of Figure 9 are for the 314 SF galaxies (among 689 samples). Comparing the solid lines in Figure 9(c) and Figure 9(f), it shows that these 314 galaxies are more metal-rich than the 74 galaxies in our main working sample, which shows the aperture effect clearly, namely, the fiber observations cover more in the central parts for these 314 host galaxies, and thus they are more metal-rich than the 74 galaxies mentioned above at a given stellar mass.

When comparing Figure 9(a) and Figure 9(d), we can see that the points and dashed line (the second-order polynomial fit to the MZR for the 314 host galaxies) are generally 0.1 dex higher than the solid line (the second-order polynomial fit to the MZR of the 74 galaxies, which are shown in Figure 9(a)), at a given stellar mass. The MGS of Tremonti et al. (2004) from SDSS is also added here as the dashed line. We can see that the dashed line is close to the solid line, which suggests the distribution of 74 galaxies is consistent with that of main galaxies. From Figure 9(b) and Figure 9(e), for the comparison with the SDSS MGS as the background, it shows that the 74 galaxies are distributed nicely among the SDSS galaxies, but the 314 galaxies bias toward the more metal-rich region at a given stellar mass. These results are also the evidence that reducing the aperture bias is very necessary to present the global properties of SNe hosts.

In Figure 9(f), it is the K-S test of the oxygen abundances of the 314 SNe host galaxies with a lower light fraction. The possibilities of SNe Ia hosts and SNe II hosts being drawn from the same distribution are 0.25. This difference is less obvious than in Figure 9(c), in which the possibilities of SNe Ia hosts and SNe II hosts being drawn from the same distribution are 0.005. We hold that the difference in significance is from the aperture bias, which we have discussed above.

The differences between SNe Ia hosts and SNe Ibc hosts are not obvious in Figure 9(c) (significance as 0.9); perhaps part of the reason for this is the small size of the sample. Figure 9(f), shows that there are no significant differences between different SN types, and the K-S possibilities of SNe Ibc hosts and SNe Ia hosts being drawn from the same distribution are 0.29 here.
This result is similar to Figure 3 in Prieto et al. (2008), Prantzos & Boissier (2003), and Boissier & Prantzos (2009). This is understandable since both their samples and ours focus on SF galaxies. This is a bit different from the results in our Section 4.2, where we consider not only star forming-galaxies but also some AGNs and absorption galaxies.

6. CONCLUSIONS

In this work, we selected 902 (213+689) SNe of different types to study and compare the properties of their host galaxies. Comparison studies such as ours represent an improvement since here both SNe Ia and CC-SNe (SNe II and SNe Ibc) are considered together, and we consider different types of hosts, namely, SPSs, AGNs, and absorption galaxies, rather than only SF galaxies. The sample was obtained by cross-correlating the ASC with the SDSS DR7 MGS. In particular, we use a stricter criterion to select the sub-sample of 213 galaxies for detailed studies by requiring the 3 arcsec SDSS fiber observations to cover at least 15% of the light of all galaxies so that the spectra can represent the global properties of the entire galaxies. The remaining 689 galaxies with a lower light fraction of spectral observations are taken as a comparison sub-sample. Then the aperture effect/bias is shown clearly by comparing these two sub-samples. The sample includes Type Ia, Type II, and Type Ibc SNe hosts, so we can compare the environments and properties of these different types of hosts at the same time.

Thanks to the SDSS observing the high-quality optical spectra and the MPA/JHU group publishing the property parameters of the galaxies, we can then compare and study the sample galaxies in detailed stellar population analysis and in some interesting relations.

We summarize our results as follows.

1. We further classify the sample galaxies by their emission-line ratios on the BPT diagram. Among the 213 sample galaxies, 135 of them can be plotted on the BPT diagram, including 82 SF galaxies and 53 AGNs (including composites, LINERs, and Seyfert 2s). The other 78 cannot be included on the BPT diagram because they are absorption-(and weak emission-) line galaxies (called Absorps; see Table 2).

2. As shown in Figure 5, almost all the Type II SNe occur in SF galaxies, and only very few are in the AGNs and weak emission-line galaxies. Most of the SNe Ibc are also in SF galaxies. The majority of the Type Ia SNe occur in AGNs and Absorp galaxies and about one-third in SF galaxies. The SF host galaxies have a wide range of stellar masses, from log(M/M_⊙) ~ 8 to 11. However, the host galaxies of SNe are massive when they are AGNs and Absorps, mostly with log(M/M_⊙) > 10, and the Absorps host galaxies are even more massive, up to 11.6.

3. When we put all these SNe host galaxies together in the relations of D_L/(4000) versus Hα, stellar mass versus D_L/(4000), stellar mass versus SFRs and sSFRs, two groups for SF and a significant number of Absorps & AGNs can be shown as the hosts, but the remaining AGNs & Absorps are in the middle and even mixed with the corner of the SF galaxies. This is especially clear in the relation of stellar masses versus SFRs and sSFRs as shown in Figure 5. Thus, the SNe host galaxies fall well within the global SDSS sample, but preferentially occupy some sub-regions of the diagrams depending on the properties of their hosts.

4. The K-S test of the cumulative fraction for stellar population analysis from spectral synthesis fitting shows that the hosts of Type II SNe have a younger stellar population and are younger than the hosts of Type Ia SNe. The hosts of SNe Ia have more metal-rich stellar populations and are more metal-rich than hosts of SNe II. The differences between the hosts of SNe Ibc and the hosts of other two types of SNe are not obvious.

5. The same relations of parameters describing properties have been made for the comparison sample with 689 galaxies. The AGN fraction of the sample is higher than that of the 213 objects since only the nuclei region is covered in the fiber targeting the large galaxies.

6. The stellar mass–metallicity relations of the SF galaxies in the two sub-samples are also presented. In the MZR, our main working sample of the galaxies with a higher light fraction of spectral observations is closer to the SDSS MGS galaxies, but the comparison sample is about 0.1 dex higher in 12+log(O/H) at a given stellar mass. This confirms that the aperture effect of spectral observations should be taken into account when we try to understand the properties of SN host galaxies. The K-S test for the comparison sample (Figure 9(f)) shows that there are no significant differences between hosts of different SN types. We should keep in mind that only SF galaxies are considered here.

In this work, we have concentrated on the properties of the SNe hosts. However, we could not give more restrictions on the progenitors of SNe, and the relations between the host properties and properties of the SNe themselves, such as the decline time, the stretch, the SNe peak luminosity, or the SNe rates. These should be discussed in future studies.

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