Supernovae and their host galaxies – V. The vertical distribution of supernovae in disc galaxies

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ABSTRACT

We present an analysis of the height distributions of the different types of supernovae (SNe) from the plane of their host galaxies. We use a well-defined sample of 102 nearby SNe appeared inside high-inclined (i ≥ 85°), morphologically non-disturbed SO–Sd host galaxies from the Sloan Digital Sky Survey. For the first time, we show that in all the subsamples of spirals, the vertical distribution of core-collapse (CC) SNe is about twice closer to the plane of host disc than the distribution of SNe Ia. In Sb–Sc hosts, the exponential scale height of CC SNe is consistent with those of the younger stellar population in the Milky Way (MW) thin disc, while the scale height of SNe Ia is consistent with those of the old population in the MW thick disc. We show that the ratio of scale lengths to scale heights of the distribution of CC SNe is consistent with those of the resolved young stars with ages from ~10 Myr up to ~100 Myr in nearby edge-on galaxies and the unresolved stellar population of extragalactic thin discs. The corresponding ratio for SNe Ia is consistent with the same ratios of the two populations of resolved stars with ages from a few 100 Myr up to a few Gyr and from a few Gyr up to ~10 Gyr, as well as with the unresolved population of the thick disc. These results can be explained considering the age-scale height relation of the distribution of stellar population and the mean age difference between Type Ia and CC SNe progenitors.

Key words: supernovae: general – galaxies: spiral – galaxies: stellar content – galaxies: structure – Galaxy: disc.

1 INTRODUCTION

The detailed understanding of the spatial distribution of Supernovae (SNe) in galaxies provides a strong possibility to find the links between the nature of their progenitors and host stellar populations (e.g. van den Bergh 1997; Ivanov et al. 2000; Petroanian et al. 2005; Anderson & James 2008; Hakobyan et al. 2008, 2009; Kelly & Kirshner 2012; Nazaryan et al. 2013; Galbany et al. 2014; Taddia et al. 2015; Aramyan et al. 2016). Such studies allow to constrain the important physical parameters of the different SN progenitors like their masses (e.g. Anderson et al. 2012; Kangas et al. 2017), ages (e.g. McMillan & Ciardullo 1996; Förster & Schawinski 2008), and metallicities (e.g. Modjaz et al. 2011; Galbany et al. 2016). For a comprehensive review addressing these issues, the reader is referred to Anderson et al. (2015).

According to the properties of SNe progenitors, they are divided into two general categories: core-collapse (CC) and Type Ia (thermonuclear) SNe. CC SNe are the colossal explosions that mark the violent deaths of young massive stars (e.g. Turatto 2003; Smartt 2009; Smith et al. 2011), while SNe Ia are the explosive end in the evolution of binary stars in which one of the stars is an older white dwarf (WD) and the other star can be anything from a giant star to a WD (for a comprehensive review about thermonuclear SNe, see Maoz, Mannucci & Nelemans 2014). Type Ia SNe result from stars of different ages (from ~0.5 Gyr up to ~10 Gyr, see Maoz & Mannucci 2012), with longer progenitors lifetime than the progenitors of CC SNe (from a few Myr up to ~0.2 Gyr when including the evolution of stars in close binary systems, see Zapartas et al. 2017).

1 According to the spectral features in visible light, CC SNe are classified into three basic classes (e.g. Filippenko 1997): hydrogen lines are visible in the spectra of Type II SNe, but in Types Ib and Ic SNe; helium lines are seen in the spectra of SNe Ib, but in SNe Ic. Subclass IIn SNe are dominated by narrow emission lines, while subclass Ibb SNe have transitional spectra closer to SNe II at early times, then evolving to SNe Ib.
Usually, the spatial distribution of SNe in S0–Sm galaxies is studied with the reasonable assumption that all CC SNe and the vast majority of SNe Ia belong to the disc, rather than the bulge population (e.g. van den Bergh 1997; Ivanov et al. 2000; Petrovskii et al. 2005; Hakobyan 2008; Anderson & James 2008; Wang et al. 2013). Moreover, the distributions of SNe in the disc are studied assuming that the disc is infinitely thin (e.g. Hakobyan et al. 2009; Wang et al. 2013). The height distribution of SNe from the disc plane is mostly neglected when studying the host galaxies with low inclinations (close to face-on orientation) assuming that the exponential scale length of the radial distribution is dozens of times larger in comparison with the exponential scale height of SNe (e.g. Hatano et al. 1998).

Direct measurements of the heights of SNe and estimates of the scales of their vertical distributions in host galaxies with high inclination (close to edge-on orientation) were performed only in a small number of cases (McMillan 1997; Molloy 2012; Pavlyuk & Tsvetkov 2016). Mainly due to the small number statistics of SNe and inhomogeneous data of their host galaxies, the comparisons of vertical distributions of the different types of SNe resulted in statistically insignificant differences. Therefore, while the detailed study of the vertical distributions in edge-on galaxies has allowed to constrain ages, masses and other physical parameters of their components (e.g. Seth et al. 2005; Yoachim & Dalcanton 2006; Bizyaev et al. 2014), the lack of analogous studies on the distribution of various SN types has prevented the determination of their parent populations via the direct comparison with the nearby extragalactic discs and the thick/thin discs of the Milky Way (MW) galaxy (e.g. Chen et al. 2001; Larsen & Humphreys 2003; Juric et al. 2008).

The purpose of this paper is to address these questions properly through an investigation of the vertical distributions of the main classes of SNe in a nearby sample of 102 SNe and their well-defined edge-on S0–Sd host galaxies from the Sloan Digital Sky Survey-III (SDSS-III; Alam et al. 2015).

This is the fifth article of the series and the content is as follows. Sample selection and reduction are introduced in Section 2. Section 3 describes the stellar disc model that we use to fit our data. All the results are discussed in Section 4. Section 5 summarizes our conclusions. To conform to values used in our data base (Hakobyan et al. 2012, hereafter Paper I), a cosmological model with \( \Omega_m = 0.27, \Omega_{\Lambda} = 0.73, \) and \( H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1} \) Hubble constant (Sp Berger et al. 2007) are adopted in this article.

## 2 Sample Selection and Reduction

In this paper, we composed our sample by cross-matching the coordinates of classified Ia, Ibc, and II SNe from the Asiago Supernova Catalogue (ASC; Barbon et al. 1999) with the footprint of SDSS Data Release 12 (DR12; Alam et al. 2015). All SNe are required to have equatorial coordinates. We use SDSS DR12 and the approaches presented in Paper I to identify the host galaxies and classify their morphological types. It is worth noting that morphological classification of nearly edge-on galaxies is largely based on the visible size of bulge relative to the disc because other morphological properties, such as the shape of spiral arms or presence of the bar, are generally obscured or invisible. The morphologies of galaxies are restricted to S0–Sd types, since we are interested in studying the vertical distribution of SNe in host stellar discs. A small number of Sdm–Sm host galaxies are not selected, because they show no clear discs.

From the signs of galaxy–galaxy interactions, we classify the morphological disturbances of the hosts in the SDSS DR12 following the techniques described in detail in Hakobyan et al. (2014, hereafter Paper II). We then exclude from this analysis any galaxy disc exhibiting strong disturbances: interacting, merging, and post-merging/remnant.

Using the techniques presented in Paper I, we measure the apparent magnitudes and the geometry of host galaxies. In the SDSS g-band, we first construct isophotes, and then centred at each galaxy centroid position an elliptical aperture visually fitted to the 25 mag arcsec^{-2} isophote. We measure the apparent magnitudes, major axes (D_{25}), position angles (PA) of the major axes, and elongations (a/b) of galaxies using these apertures. In this analysis, we correct the magnitudes and D_{25} for Galactic and host galaxy internal extinction (see Paper I).

### 2.1 Inclination

The main difficulty in measuring the vertical distribution of SNe above the host stellar discs is that we have no way of knowing where along the line of sight the SNe lie. This means that reliable measurements can only be done in discs which are highly inclined, i.e., closer to an edge-on orientation (e.g. 85° < i < 90°). In contrast to galaxies with lower inclination, the matter is complicated by the difficulty of making an accurate determination of the inclination angle. For these galaxies, the inclination cannot be measured simply from the major and minor axes because the presence of a central bulge places a limit on the axis-ratio even for a perfectly edge-on galaxy.

This problem with the bulge has been solved by using the axial ratio of the exponential disc fits in the g-band provided by the SDSS (from the model with r^{1/4} bulge and exponential disc), i.e., \( e^{\text{expAB}_{i,j}} \). Indeed, real stellar discs are not flat with negligible thicknesses, but have some intrinsic width, and a proper measurement of the inclination depends on this intrinsic ratio of the vertical and horizontal axes of the disc, known as \( q \). Therefore, we calculate the inclinations of SNe host galaxies following the formula

\[
\cos^2 i = \frac{(e^{\text{expAB}_{i,j}})^2 - q^2}{1 - q^2},
\]

where \( i \) is the inclination angle in degrees between the polar axis and the line of sight and \( q \) is the intrinsic axis-ratio of galaxies viewed edge-on. According to Paturel et al. (1997),

\[
q = \text{dex}[-(0.43 + 0.053 t)]
\]

for \(-1 \leq t \leq 7\), where \( t \) is the morphological type code. Using equations (1) and (2), we restrict the inclinations of host galaxies to 85° < i < 90°.

All the selected SNe host galaxies are visually inspected because sometimes bright stars projected nearby, strong dust layers, bright nuclear/bulge emission, large angular sizes, etc. do not allow

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2 ‘Stripped-envelope’ SNe of Types Ib and Ic, including the mixed Ib/c with uncertain subclassification, are denoted as SNe Ib/c.

3 We use the updated version of the catalogue, which includes all classified SNe exploded before 2015 January 1.

4 Instead using the data from Paper I, which is based on the SDSS DR8, for homogeneity we re/measure the magnitudes and the geometry of all host galaxies, with additional new SN hosts included, based only on DR12.
the SDSS automatic algorithm to correctly determine the parameters of galaxies, in particular the axis-ratio $e_{\exp AB}$. The host discs with a clearly seen dust layer, or without signs of non-edge-on spiral arms, are selected as true edge-on galaxies. In other words, we exclude the discs whose galactic plane is not aligned along the major axis of their fitted elliptical apertures (e.g. warped edge-on discs, see Reshetnikov et al. 2016). As a result, we select 106 SNe in edge-on host galaxies.

In S0–Sd galaxies, all CC SNe and the vast majority of Type Ia SNe belong to the disc, rather than the bulge component (Hakobyan et al. 2016, hereafter Paper III). Therefore, for the selected 106 SNe in this restricted sample of edge-on galaxies, we perform a visual inspection of the SNe positions on the SDSS images to identify the SNe from the bulge population of host galaxies. The result is that three Type Ia (1990G, 1993aj, and 2003ge) and one Type Ibc (2005E) SNe may belong to the bulge because of their location. The three SNe Ia are clearly outside the host discs, located far in the bulge population. The Type Ibc SN is also located far from the host galaxy disc but it is a peculiar, calcium-rich SN whose nature is still under debate and may have a different progenitor from typical CC (e.g. Perets et al. 2010). All these four SNe are excluded from the sample.

After these restrictions, we are left with a sample of 102 SNe within 100 host galaxies. The mean distance of this sample is 100 ± 8 Mpc, the median distance and standard deviation are 78 Mpc and 84 Mpc, respectively. The mean $D_{25}$ of our host galaxies is 108 ± 10 arcsec with the smallest value of 22 arcsec. Table 1 displays the distribution of all SNe types among the various considered morphological types of host galaxies. Fig. 1 shows images of typical examples of edge-on host galaxies with marked positions of SNe.

### 2.2 Measurements of the heights of SNe

The heights of SNe above host galactic plane might be calculated by using the simple formulas presented in Hakobyan et al. (2009) with available SNe offsets from host galaxy nuclei and PA of the galaxies (see also Paper III). However, as demonstrated in Paper I, SN catalogs report different offsets with different levels of accuracy. Individual offsets are based on the determination of the positions of the host galaxy nuclei, which might be uncertain and depend on many factors (e.g. colour of image, plate saturation, galaxy peculiarity, incorrect SDSS fiber targeting of the galaxy nucleus, etc.). For more details, the reader is referred to Paper I.

For this study, using the SN coordinates and its edge-on host galaxy image in the SDSS $g$-band, we measure the perpendicular distance, i.e., the height, from the major axis of the fitted elliptical aperture of each galaxy to the position of SN. At the same time, using the coordinates of the host galaxy nucleus, we also measure the projected galactocentric radius of SN along the same major axis. Fig. 2 schematically illustrates the geometrical location of an SN within an edge-on disc, where V is the height (in arcsec) and U is the projected galactocentric radius (in arcsec) of the SN. A similar technique was also used in Pavlyuk & Tsvetkov (2016) on the Digital Sky Survey (DSS) images to determine the V and U coordinates of SNe.

It is important to note that as in the case of the radial distribution of SNe in face-on galaxies (Hakobyan et al. 2009), the distribution of linear distances in the vertical direction is biased by the greatly different intrinsic sizes of host discs. Fig. 3 illustrates the comparison of the heights V of SNe and $R_{25}$ of host galaxies in kpc. Also shown are the best fit lines

$\log(V_{25}) = (-1.10 \pm 0.11) + (0.89 \pm 0.08) \log(R_{25})$,  

$\log(V_{CC}) = (-1.68 \pm 0.15) + (1.07 \pm 0.13) \log(R_{25})$

with near unity slopes. To check the significance of the correlations, we use the Spearman’s rank correlation test, which indicates strong positive trend between the heights and $R_{25}$ for Type Ia SNe ($r_s = 0.382, P = 0.005$), while not significant for CC SNe ($r_s = 0.166, P = 0.255$). Therefore, in the remainder of

5 We remind that in comparison with the measured heights, the measurements of projected galactocentric radii of SNe include some minor inaccuracy because of the mentioned uncertain determination of the exact point like positions of host galaxy nuclei. The projected galactocentric radii are only used in Fig. 5 of Section 4.1 for ancillary purposes.
Figure 2. Location of the SN within its edge-on host galaxy. The center of the galaxy is at the origin of coordinate systems and the asterisk is the projected location of the SN. The U (the projected galactocentric radius) and V (the height) are coordinates of the SN in host galaxy coordinate system along the major (U) and the minor (V) axes, respectively. The inset in the upper-left corner illustrates the 90° inclination of the polar axis of the galaxy with respect to the line of sight.

this study, we use only relative heights and projected galactocentric radii of SNe, i.e., normalized to $R_{25} = D_{25}/2$ of host galaxies in g-band.

The full data base of 102 individual SNe (SN designation, type, equatorial coordinates, v and U) and their 100 host galaxies (galaxy SDSS designation, distance, morphological type and corrected g-band $D_{25}$) is available in the online version (Supporting Information) of this article.

3 THE MODEL OF STELLAR DISC

In our model, the volumetric density $\rho_{SN}(\tilde{r}, \tilde{z})$ of SNe in the host axisymmetric stellar discs is assumed to vary as follows in the radial $\tilde{r}$ and vertical $\tilde{z}$ directions:

$$\rho_{SN}(\tilde{r}, \tilde{z}) = \rho_0^{SN} \exp(-\tilde{r}/\tilde{H}_{SN}) f(\tilde{z}),$$

where $\tilde{r} = R_{SN}/R_{25}$, $\tilde{z} = z_{SN}/R_{25}$ and ($R_{SN}, z_{SN} \equiv v$) are cylindrical coordinates, $\rho_0^{SN}$ is the central volumetric density, $\tilde{H}_{SN} = h_{SN}/R_{25}$ is the radial scale length, and $f(\tilde{z})$ is a function describing the vertical distribution of SNe.

In equation (3), we adopt a generalized vertical distribution

$$f(\tilde{z}) = \text{sech}^{2n}\left(n\tilde{z}/z_0^{SN}\right),$$

where $z_0^{SN} = z_{0SN}/R_{25}$ is the vertical scale height of SNe and $n$ is a parameter controlling the shape of the profile near the plane of host galaxy. Following the vertical surface brightness distribution of edge-on galaxies (e.g. de Grijs et al. 1997; Bizyaev & Mitronova 2002), we also assume that the scale height of SNe is independent of projected galactocentric radius (see also de Grijs & Peletier 1997, for late-type galaxies), i.e., there is no disc flaring.

Recent photometric fits to the surface brightness distribution of a large number of edge-on galaxies in near-infrared (Mosenkov et al. 2010) and SDSS g-, r-, and i-bands (Bizyaev et al. 2014, see also Yoachim & Dalcanton 2006 for other photometric bands) suggest that a value of $n = 1$ is an appropriate model of stellar discs. When $n \rightarrow \infty$, equation (4) reduces to $f(\tilde{z}) \sim \exp(-|\tilde{z}|/\tilde{H}_{SN})$, where $\tilde{H}_{SN} = z_0^{SN}/2$ at large heights, and is widely used to successfully fit the dust distribution in edge-on galaxies (e.g. Bianchi 2007; Bizyaev et al. 2014).

In linear units, the exponential ($\exp$) form of $f(\tilde{z})$ is used to model the distribution of Galactic stars (e.g. Chen et al. 2001; Larsen & Humphreys 2003), novae (e.g. Hatano et al. 1997a), SNe (e.g. Dawson & Johnson 1994; Hatano et al. 1997b), SN remnants (e.g. Ilovaisky & Lequeux 1972), pulsars (e.g. Andreasyan et al. 2016), and extragalactic SNe (e.g. McMillan 1997; Hatano et al. 1998; Pavlyuk & Tsvetkov 2016), while the sech$^2$ form is used to fit the vertical distribution of resolved stars (Seth et al. 2005) and CC SNe (Molloy 2012) in highly inclined nearby galaxies.

Note that sech$^2$ profile ($n = 1$) is expected for an isothermal stellar population (Spitzer 1942), while exp profile ($n \rightarrow \infty$) can be obtained by a combination of isothermal stellar populations with different “temperatures” (velocity dispersions). While at large heights, sech$^2(x) \rightarrow 4\exp(-2x)$, at low heights, the sech$^2$ profile is uniform, while the exp profile is cuspy.

4 RESULTS AND DISCUSSION

4.1 The vertical distribution and scale height of SNe

We fit sech$^2$ and exp forms of $f(\tilde{z})$ profile to the distribution of normalized absolute heights ($|\tilde{z}| \equiv |v|/R_{25}$) of SNe, using maximum likelihood estimation (MLE). Here, because of the small number statistics of Type Ibc SNe (see Table 1), we group them with Type II SNe in a larger CC SNe sample. Fig. 4 shows the histograms of the normalized heights with the fitted sech$^2$ and exp probability density functions (PDFs) for Type Ia and CC SNe in Sa–Sd galaxies.6 In columns 4, 7, and 10 of Table 2, we list the

6 For this comparative illustration, we do not include S0–S0a galaxies because they host almost only Type Ia SNe (see Table 1). For the sake of vi-
mean values of $|z|$ and the maximum likelihood scale heights for both types of SNe in various subsamples of host galaxies.

From column 4 of Table 2, it immediately becomes clear that in all the subsamples of host galaxies the vertical distribution of CC SNe is about twice closer to the plane of host disc than the distribution of Type Ia SNe. In fact, the two-sample Kolmogorov–Smirnov (KS) and Anderson–Darling (AD) tests, shown in Table 3, indicate that this difference is statistically significant in Sa–Sd galaxies, although not significant if only late-type hosts are considered.

Note that four Type IIb SNe are included in Type II SNe sample (see Table 1). For Sa–Sd galaxies, it might be reasonable also to group Types IIn and Ibn SNe as a wider ‘stripped-envelope’ (SE) SN class (13 objects) and compare them with pure Type II SNe (35 objects). However, we find no difference between the vertical distributions of SE and pure Type II SNe ($P_{\text{KS}} = 0.401, P_{\text{AD}} = 0.320$), resulting in statistically indistinguishable scale lengths between these SN types. Therefore, in the remainder of this study, we will group all these subtypes as the main CC SN sample and compare that with Type Ia SN sample.

It is important to note that dust extinction in edge-on host galaxies might have an impact on our estimated scale heights. In Paper I, we demonstrated that in general there is a lack of SNe host galaxies with high inclinations, which can be explained by a bias in the discovery of SNe due to strong dust extinction (e.g. Cappellaro & Turatto 1997), particularly in edge-on hosts (e.g. Holwerda et al. 2015).

The vertical distribution of dust in disc galaxies has an exponential profile with about three times smaller scale height in comparison with distribution of all stars $H_{\text{stars}}/H_{\text{dust}} \approx 3$, e.g. Bianchi 2007). Analysing the vertical distribution of the resolved stellar populations in nearby edge-on galaxies, Seth et al. (2005) found that the dust has negligible impact on the distribution parameters of stars at $|z| \geq H_{\text{dust}}$ heights (for the edge-on surface brightness profiles of unresolved populations, see e.g. Bianchi 2007). Therefore, in Table 2, to check the impact of the dust extinction on the obtained scale heights, we also estimate the distribution parameters considering the SNe in Sa–Sd galaxies only at $|z| > H_{\text{dust}}$ heights. For the average dust scale height, we use $H_{\text{dust}} = 0.02$, roughly considering that $H_{\text{dust}} \approx H_{\text{dust}}/3$ (see also Della Valle & Panagia 1992).

In Fig. 5, we show the distribution of coordinates of SNe along the major ($U/R_{25}$) and minor axes ($V \equiv V/R_{25}$) of their Sa–Sd host galaxies with the $|z| \leq 0.02$ opaque region, and for the sake of visualization, we scale the distribution to the PGC 037591 galaxy (also shown in Fig. 1, better known as NGC 3987), which is one of the representatives of the edge-on galaxies with a prominent dust line along the major axis.

From columns 7 and 10 of Table 2 (the subsamples of Sa–Sd hosts labeled with ‘+’ symbols), despite the small number statistics (column 3), we see that the extinction by dust near to the plane of host galaxies does not strongly bias the estimated scale heights of SNe. The scale height of CC SNe with $|z| > 0.02$ is almost equal to that with the $|z| \geq 0$, while the scale height of Type Ia SNe with $|z| > 0.02$ is only $\sim 15$ per cent greater (still statistically insignificant) than that with the $|z| \geq 0$. In the remainder of this study, we will generally use the scale heights of SNe without height-truncation due to the small number statistics and insignificance of the effect, however, if needed, we will emphasize the impact of the dust extinction on the scale heights.

To check whether the distribution of SN heights follows the best-fitting profiles, we perform one-sample KS and AD tests on the cumulative distribution of the normalized absolute heights ($|z|$), where the sech and $\exp$ models have $E(|z|) = \tanh(|z|/\tilde{h}_{\text{SN}})$ and $E(|z|) = 1 - \exp(-|z|/\tilde{h}_{\text{SN}})$ cumulative distribution functions (CDFs), respectively. Columns 5, 6, 8 and 9 of Table 2 show the KS and AD probabilities that the vertical distributions are statistically different from the best-fitting profiles.

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8 Another factor, such as a deviation from perfectly edge-on orientation of the host discs, may also affect our estimation of the scale heights, increasing them. However, we are quite confident that our galaxies can vary by a few degrees only from perfectly edge-on orientation (see Section 2.1). In addition, other authors have demonstrated that slight deviations from $i = 90^\circ$ have minimal impact on the derived structural parameters of the vertical distributions of different stellar populations (e.g. de Grijs et al. 1997).

9 This value can vary from two to four, depending, respectively, on early- and late-type morphology of edge-on spiral galaxies (e.g. De Geyter et al. 2014).

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**Figure 4.** Vertical distribution of SNe (scaled to isophotal radius of disc) in Sa–Sd galaxies. Upper panel: fitted sech$^2$ (dashed curve) and $\exp$ (solid curve) PDFs of the normalized absolute heights ($|z| \equiv |V|/R_{25}$) of Type Ia SNe (red histogram). Bottom panel: the same for CC SNe (blue histogram). The dark blue histogram presents the distribution of Type Ib/c SNe only. The insets present the different forms of fitted CDFs in comparison with the SN distribution. The mean values of the distributions are shown by arrows.
Figure 5. Distribution of coordinates of SNe along the major ($U/R_{25}$) and minor axes ($\xi \equiv \nu/R_{25}$) of their Sa–Sa host galaxies. Circles, triangles and crosses respectively show Types Ia, Ibc and II SNe. One-sigma intervals of the distributions of the $\xi$ coordinates for Type Ia and CC (Ibc+II) SNe are presented by dashed ($\sigma = 0.078$) and solid ($\sigma = 0.037$) lines, respectively. Background SDSS image shows the PGC 037591 galaxy (sized to the distribution), which is one of the representatives of the edge-on galaxies with a prominent dust line along the major axis. Dotted lines show the $|\xi| \leq 0.02$ opaque region.

Table 2. Consistency and scale heights of the vertical distributions of Type Ia and CC SNe in edge-on galaxies with sech$^2$ ($n = 1$) and exp ($n \to \infty$) models.

| Host | SN | $N_{SN}$ | $\langle|\xi|\rangle$ | $P_{KS}$ | $P_{AD}$ | $P_{SN}$ | $P_{KS}$ | $P_{AD}$ | $H_{SN}$ |
|------|----|---------|----------------|---------|---------|---------|---------|---------|---------|
| S0–Sd | Ia | 53 | 0.058 ± 0.009 | 0.068 | 0.012 | 0.089 ± 0.015 | 0.196 | 0.165 | 0.058 ± 0.009 |
| Sa–Sd | Ia | 44 | 0.055 ± 0.009 | 0.147 | 0.031 | 0.083 ± 0.012 | 0.319 | 0.239 | 0.055 ± 0.007 |
| Sa–Sd | CC | 48 | 0.028 ± 0.003 | 0.644 | 0.209 | 0.042 ± 0.004 | 0.648 | 0.287 | 0.028 ± 0.003 |
| Sa–Sd$^\dagger$ | Ia | 28 | 0.082 ± 0.011 | 0.983 | 0.973 | 0.098 ± 0.014 | 0.970 | 0.973 | 0.062 ± 0.012 |
| Sa–Sd$^\dagger$ | CC | 28 | 0.044 ± 0.003 | 0.459 | 0.723 | 0.041 ± 0.006 | 0.331 | 0.525 | 0.024 ± 0.004 |
| Sa–Sbc | Ia | 21 | 0.061 ± 0.014 | 0.168 | 0.055 | 0.094 ± 0.014 | 0.371 | 0.151 | 0.061 ± 0.011 |
| Sa–Sbc | CC | 21 | 0.028 ± 0.004 | 0.860 | 0.299 | 0.040 ± 0.005 | 0.492 | 0.239 | 0.028 ± 0.003 |
| Sc–Sd | Ia | 23 | 0.049 ± 0.011 | 0.627 | 0.354 | 0.073 ± 0.018 | 0.849 | 0.919 | 0.049 ± 0.009 |
| Sc–Sd | CC | 27 | 0.029 ± 0.005 | 0.493 | 0.735 | 0.044 ± 0.007 | 0.497 | 0.684 | 0.029 ± 0.004 |
| Sb–Sc | Ia | 30 | 0.064 ± 0.011 | 0.476 | 0.212 | 0.096 ± 0.016 | 0.679 | 0.482 | 0.065 ± 0.012 |
| Sb–Sc | CC | 32 | 0.028 ± 0.004 | 0.476 | 0.203 | 0.042 ± 0.007 | 0.586 | 0.264 | 0.028 ± 0.003 |
| Sb–Sc$^\dagger$ | Ia | 21 | 0.089 ± 0.013 | 0.853 | 0.962 | 0.108 ± 0.021 | 0.594 | 0.821 | 0.070 ± 0.014 |
| Sb–Sc$^\dagger$ | CC | 19 | 0.044 ± 0.004 | 0.908 | 0.948 | 0.041 ± 0.008 | 0.728 | 0.794 | 0.024 ± 0.006 |
| Sb–Sc$^*$ | Ia | 24 | 0.065 ± 0.014 | 0.686 | 0.281 | 0.097 ± 0.020 | 0.297 | 0.657 | 0.065 ± 0.014 |
| Sb–Sc$^*$ | CC | 31 | 0.028 ± 0.004 | 0.422 | 0.224 | 0.042 ± 0.007 | 0.576 | 0.335 | 0.028 ± 0.004 |

Notes. Columns 1 and 2 give the subsample; Col. 3 is the number of SNe in the subsample; Col. 4 is the mean of normalized absolute vertical distribution with the error of the mean; Cols. 5 and 6 are the $P_{KS}$ and $P_{AD}$ probabilities from one-sample KS and AD tests, respectively, that the vertical distribution of SNe is drawn from the best-fitting sech$^2$ profile; Col. 7 is the maximum likelihood value of the scale height with bootstrapped error (repeated 10$^3$ times); Cols. 8, 9, and 10 are, respectively, the same as Cols. 5, 6, and 7, but for the best-fitting exp profile. The subsamples labeled with $^\dagger$ symbols correspond to SNe with $|\xi| > 0.02$. The subsamples labeled with $^*$ symbols correspond to SNe with distances $\leq 200$ Mpc.

We calculate the $P_{KS}$ and $P_{AD}$ using the calibrations by Massey (1951) and D’Agostino & Stephens (1986), respectively. The statistically significant deviations from the best-fitting profile are highlighted in bold.

drawn from the best fitting profile. Cumulative distributions of the heights and CDFs of the fitted forms for Type Ia and CC SNe in Sa–Sd galaxies are presented in the insets of Fig. 4.

From columns 5, 6, 8 and 9 of Table 2, we see that the vertical distribution is consistent with both profiles in most subsamples of Type Ia SNe and in all subsamples of CC SNe. For Type Ia SNe in Sa–Sd (also in S0–Sd) galaxies, the vertical distribution is consistent with the exp profile, but not with the sech$^2$ one (as seen in the AD statistic but only very marginally in the KS statistic). When we separate SNe Ia between early- and late-type host galaxies, the inconsistency vanishes with only barely AD test significance in early-type spirals (see the $P_{AD}$ value in column 6 of Table 2 for SNe Ia in Sa–Sbc galaxies). The $\langle|\xi|\rangle$ value (scale heights too) for SNe Ia is $\sim 25$ per cent greater in Sa–Sbc galaxies than in Sc–
Most recently, Pavlyuk & Tsvetkov (2016) studied the absolute (in kpc) and relative (normalized to radius of host galaxy) vertical distributions of SNe using a sample of 26 Type Ia, 8 Ib, and 44 II SNe in spiral host galaxies with $i \geq 85^\circ$. They found that the distributions can be fitted by exp profiles with scale heights $H_\perp = 0.030 \pm 0.006$, $H_{\text{tot}} = 0.024 \pm 0.006$, and $H_{\|} = 0.029 \pm 0.005$. The scale heights for Type Ibc and II SNe are in good agreement with our $H_{\text{CC}} = 0.028 \pm 0.003$ in Sa–Sd galaxies, while their scale height for Type Ia SNe is much smaller than ours $H_{\perp} = 0.055 \pm 0.007$ in the same morphological bin. However, the direct comparison of the scale heights obtained by Pavlyuk & Tsvetkov with ours is difficult because they used the SDS images for reduction of SNe host galaxies without mentioning the photometric band (we assume that they used $B$-band), while we use the SDSS $g$-band to normalize the heights to the $25^{\text{th}}$ magnitude isophotal semimajor axes of host galaxies. On the other hand, we are not able to check the consistency between the morphological distributions of edge-on galaxies hosting Type Ia and CC SNe in their and our samples because morphological types were not provided by Pavlyuk & Tsvetkov.

To exclude any dependence of scale height of host stellar population on the morphological type, we analyse the vertical distribution of SNe in the most populated morphological bins, i.e., in the narrower Sc–Sd subsample (see Table 1).11 In addition, the Sc–Sd subsample is more suitable for comparison of the estimated vertical scale heights of SNe with those of different stellar populations of thick and thin discs of the MW galaxy (see Section 4.2), and to exclude a small number of very thin discs (see e.g. Bizyaev et al. 2017), which usually appear in late-type galaxies. From Table 2, we conclude that the vertical distributions of Type Ia and CC SNe in Sc–Sd galaxies can be well fitted by both the sech$^2$ and exp profiles. The vertical distribution of CC SNe is significantly different from that of Type Ia SNe (Table 3), being 2.3$\pm0.5$ times more concentrated to the plane of the host disc (Table 2). This difference also exists when the above-mentioned effect of the dust extinction is considered for the particular subsample (Sc–Sd hosts labeled with ‘$\ddagger$’ symbols in Tables 2 and 3). In Fig. 6, we present the comparison of vertical distributions as well as the fitted sech$^2$ and exp CDFs between both the types of SNe in Sc–Sd host galaxies.

It is important to note that Type Ia SNe, because of their comparably high luminosity (in about two absolute magnitudes in $B$-band, e.g. Richardson et al. 2002) and the presence of dedicated surveys, are discovered at much greater distances than CC SNe (see Paper I). To check the possible distance biasing on the vertical distribution of SNe, we truncate the sample of Sc–Sd galaxies to distances $\leq 200$ Mpc.12 In Table 2, the comparison of $\langle |\tilde{z}| \rangle$, $\Delta z_{50}$, and $\Delta z_{90}$ with the hosts of SNe, the distribution is (in kpc) of 64 CC SNe in highly inclined ($i \geq 80^\circ$) Sa–Sd host galaxies. He showed that the distribution can be well fitted by a sech$^2$ profile. However, these studies only used linear scales to estimate the vertical distribution of SNe. This is somewhat undesirable because the absolute distribution of SN heights (in kpc) is biased by the greatly different intrinsic sizes of host discs (as already shown in Fig. 3).

### Table 3. Comparison of the normalized absolute vertical distributions ($|\tilde{z}| \equiv |\tilde{z}|/R_{25}$) of SNe among different pairs of subsamples.

| Subsample 1 | Subsample 2 | $P_{KS}$ | $P_{AD}$ |
|-------------|-------------|----------|----------|
| Host SN     | $N_{SN}$    | Host SN  | $N_{SN}$ | $P_{KS}$ | $P_{AD}$ |
| Sa–Sd       | 44          | Sa–Sd    | 48       | 0.045    | 0.025    |
| Sa–Sd$^\ddagger$ | 28       | Sa–Sd$^\ddagger$ | 28    | 0.011    | 0.003    |
| Sa–Sc       | 21          | Sa–Sc    | 21       | 0.041    | 0.037    |
| Sc–Sc       | 23          | Sc–Sc    | 27       | 0.690    | 0.310    |
| Sa–Sc$^\ddagger$ | 21       | Sc–Sc    | 23       | 0.387    | 0.440    |
| Sb–Sc$^\ddagger$ | 30       | Sb–Sc$^\ddagger$ | 32    | 0.039    | 0.009    |
| Sb–Sc$^\ddagger$ | 21       | Sb–Sc$^\ddagger$ | 19    | 0.013    | 0.001    |
| Sb–Sc$^\ddagger$ | 24       | Sb–Sc$^\ddagger$ | 31    | 0.112    | 0.028    |

Notes: The subsamples labeled with ‘$\ddagger$’ symbols correspond to SNe with $|\tilde{z}| > 0.02$. The subsamples labeled with ‘$\ast$’ symbols correspond to SNe with distances $\leq 200$ Mpc. The $P_{KS}$ and $P_{AD}$ are the probabilities from two-sample KS and AD tests, respectively, that the two distributions being compared are drawn from the same parent distribution. The $P_{KS}$ and $P_{AD}$ are calculated using the calibrations by Massey (1951) and Pettitt (1976), respectively. The statistically significant differences between the distributions are highlighted in bold.

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10 Type Ibc SNe were labelled as ‘Ipec’ types during observations before 1986 and included in the sample of Type I SNe.

11 On the other hand, by selecting these bins we reduce the possible contribution by SNe Ia from central bulges of host galaxies, although the bulge contribution is only up to 9 per cent of the total SN Ia population in Sa–Sd host galaxies (Barkhudaryan et al. in preparation).

12 It would be more effective to check this with distance-truncation at 150 (100) Mpc (see Papers II and III), however the remaining statistics in this case is very low, which destroys any comparison with significance. With
\( H_{SN} \) as well as \( P_{KS} \) and \( P_{AD} \) values of distance-truncated sample (labeled with ‘\*’ symbols) with those of Sb–Sc host galaxies allows to conclude that possible distance biasing in our sample is negligible. Due to the smaller number statistics, we get larger error bars in Table 2, and lose only the KS test significance in Table 3. Therefore, in the remainder of this study, we will use SNe in Sb–Sc galaxies without distance-truncation.

### 4.2 The thick and thin discs

It is largely accepted that the disc of the MW, one of the well-studied representatives of Sb–Sc classes, is separated into at least three components/populations: (1) the youngest star-forming disc (\( \tilde{H} \leq 0.01 \)), including molecular clouds and massive young stars; (2) the younger thin disc (\( \tilde{H} \sim 0.02 \)), which contains stars with a wide range of ages; and (3) the old thick disc (\( \tilde{H} \sim 0.06 \)), composed almost exclusively of older stars (Gilmore & Reid 1983; Robin et al. 1996; Ng et al. 1997; Buser et al. 2001; Larsen & Humphreys 2003; Larsen & Humphreys 2003). For extragalactic discs of nearby edge-on spirals, the thick and thin components are also resolved (e.g. Seth et al. 2005; Yoachim & Dalcanton 2006). In this sense, we may be able to put constraints on the nature of the progenitors of Type Ia and CC SNe by comparing the parameters of their distributions (\( H_{SN} \) or \( z_{SN}^0 \) and \( h_{SN}/z_{SN}^0 \) or \( h_{SN}/H_{SN} \)) in edge-on Sb–Sc galaxies with those of different stellar populations of thick and thin discs of MW and other similar galaxies. Note that the mean luminosity of our sample of Sb–Sc host galaxies (\( \langle M_g \rangle = -20.5 \pm 1.0 \)) is in good agreement with that of the MW (\( \langle M_g \rangle = -21.0 \pm 0.5 \), Licquia et al. 2015).

In Table 4, we list the \( \exp \) scale heights of SNe estimated in this study and the \( \exp \) scale heights of the MW thick and thin discs derived from star counts (from hundreds of thousands to millions of individual stars) by other authors. As can be seen, the scale height of the vertical distribution of CC SNe is consistent with those of younger stellar population in the thin disc (a wide range of ages up to a few Gyr, Loebman et al. 2011), while the scale height of Type Ia SNe is consistent with those of old population in the thick disc (from a few Gyr up to \( \sim 10 \) Gyr, Loebman et al. 2011) of the MW galaxy.

Note that, in Table 4, the MW \( \tilde{H} \) values are calculated using the original values of \( H \) from the references and assuming \( R_{25}^{MW} = 15 \pm 1 \) kpc. The \( \tilde{H} \) values are listed in ascending order.

| Host          | \( \tilde{H} \) | Reference          |
|---------------|----------------|--------------------|
| MW thick disc | 0.020 ± 0.005  | Jurić et al. (2008) |
| MW thick disc | 0.022 ± 0.003  | Chen et al. (2001) |
| MW thick disc | 0.022 ± 0.005  | Larsen & Humphreys (2003) |
| SNe CC (Sb–Sc) | 0.028 ± 0.003 | This study         |
| MW thick disc | 0.050 ± 0.005  | Chen et al. (2001) |
| MW thick disc | 0.051 ± 0.005  | Robin et al. (1996) |
| MW thick disc | 0.057 ± 0.014  | Ojha (2001)        |
| MW thick disc | 0.058 ± 0.005  | Larsen & Humphreys (2003) |
| MW thick disc | 0.060 ± 0.013  | Jurić et al. (2008) |
| MW thick disc | 0.061 ± 0.020  | Buser et al. (1999) |
| SNe Ia (Sb–Sc) | 0.065 ± 0.012 | This study         |
| MW thick disc | 0.067 ± 0.008  | Ng et al. (1997)   |

Notes. The MW \( \tilde{H} \) values are calculated using the original values of \( H \) from the references and assuming \( R_{25}^{MW} = 15 \pm 1 \) kpc, i.e., \( \tilde{H} = H/R_{25}^{MW} \), while the ratio of radial to vertical scales (\( h/R \)) would be better for a comparison of SNe distribution with the distribution of stars in the MW, avoiding the use of ambiguous value of \( R_{25}^{MW} \).

In Paper III, we studied the radial distributions of SNe and estimated the scale lengths of Type Ia and CC SNe using a well-defined sample of 500 nearby SNe and their low-inclined (\( \leq 60^\circ \)) and morphologically non-disturbed S0–Sm host galaxies from the SDSS. In particular, the radial distributions of Type Ia and CC SNe in spiral galaxies are consistent with one another and with an exponential surface density according to \( \exp(-\tilde{r}/h_{SN}) \) in equation (3) where \( \tilde{r} = R_{SN}/R_{25} \) and \( h_{SN} = h_{SN}/R_{25} = 0.21 \pm 0.02 \). However, to be consistent with the present study, we use the estimation of the scale lengths of SNe restricted to Sb–Sc host galaxies from that sample. Note that the similar determination of the sample of the present paper is not possible because of its extreme inclination. For both types of SNe, we find \( h_{SN} = 0.20 \pm 0.02 \) using 79 Type Ia and 198 CC SNe.

In Table 5, we list the ratios of radial to vertical scales of SNe (\( h_{SN}/H_{SN} \) or \( h_{SN}/H_{SN} \)) estimated in this study and the analogous ratios of MW thick and thin discs derived from star counts by other authors. The ratio of scales of CC SNe appears consistent with those of the younger stellar population in the thin disc, while the corresponding ratio of Type Ia SNe is consistent with the old population in the thick disc of the MW (although on the small side).

It should be noted that the parameters of the vertical distributions of different stellar populations in the MW are determined using samples dominated by stars relatively near the Sun, not including the sizable population of the disc (see the discus-

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The mentioned distance-truncation, we have only 19 (9) Type Ia SNe with \( \langle z \rangle = 0.071 \pm 0.019 \) (0.086 ± 0.025) and 30 (24) CC SNe with \( \langle z \rangle = 0.027 \pm 0.005 \) (0.031 ± 0.006).

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\( H_{SN} \) as well as \( P_{KS} \) and \( P_{AD} \) values of distance-truncated sample (labeled with ‘\*’ symbols) with those of Sb–Sc host galaxies allows to conclude that possible distance biasing in our sample is negligible. Due to the smaller number statistics, we get larger error bars in Table 2, and lose only the KS test significance in Table 3. Therefore, in the remainder of this study, we will use SNe in Sb–Sc galaxies without distance-truncation.
sion in Bovy et al. 2012). Therefore, the structural parameters of the MW may be different from those of other galaxies. In particular, Seth et al. (2005) analysed the vertical distribution of the resolved stellar populations in nearby six edge-on Sc galaxies observed with the Hubble Space Telescope and found that the ratios of radial to vertical scales of young star-forming discs are much smaller (∼ 3–4 times) than that of the MW. In other words, the young star-forming discs of their sample galaxies are much thicker in comparison with that of the MW. Their results are in agreement with those of Yoachim & Dalcanton (2006), who analysed the vertical structure of 34 late-type, edge-on, undisturbed disc galaxies using the two-dimensional fitting to their photometric profiles.

Interestingly, Seth et al. (2005) found that the scale height of a stellar population increases with age, which is also correct for the MW galaxy (e.g. Chen et al. 2003; Bovy et al. 2012). They used colour-magnitude diagrams (CMDs) to estimate the ages of resolved stellar populations (see figs. 1 and 4 in Seth et al. 2005). The young population in their main-sequence (MS) box of the CMD is dominated by stars with ages from ∼ 10 Myr up to ∼ 100 Myr, the intermediate population in the asymptotic giant branch (AGB) box is dominated by stars with ages from a few 100 Myr up to a few Gyr, while the old population in the red giant branch (RGB) box is dominated by stars with ages from a few Gyr up to ∼ 10 Gyr. In light of this, we compare in Table 6 the ratios of radial to vertical scales of SNe with those detected from resolved stars in nearby edge-on late-type galaxies (e.g. Seth et al. 2005) and from unresolved populations of extragalactic thick and thin discs estimated using the edge-on surface brightness profiles (e.g. Yoachim & Dalcanton 2006; Bizyaev et al. 2014).

In Table 6, we see that the ratio of scales of the distribution of CC SNe is consistent with those of the resolved MS-box stars in Seth et al. (2005) and unresolved stellar population of the thin disc in Yoachim & Dalcanton (2006). On the other hand, the $h_{\text{SN}}/z_{\text{SN}}$ ratio of Type Ia SNe is consistent and located between the values of the same ratios of resolved RGB- and AGB-box stars, respectively (Seth et al. 2005). In addition, the $h_{\text{SN}}/z_{\text{SN}}$ ratio of Type Ia SNe is consistent with those of the unresolved population of the thick disc in Yoachim & Dalcanton (2006) and with the thick+thin disc population in Bizyaev et al. (2014).

These results are in good agreement with the age-scale height relation of stars in galaxy discs (e.g. Seth et al. 2005; Bovy et al. 2012), and that Type Ia SNe result from stars of different ages (from ∼ 0.5 Gyr up to ∼ 10 Gyr, see Maoz & Mannucci 2012), with even the shortest lifetime progenitors having much longer lifetime than the progenitors of CC SNe (from a few Myr up to ∼ 0.2 Gyr, see Zapartas et al. 2017).

Supernovae and their host galaxies – V

5 CONCLUSIONS

In this fifth paper of a series, using a well-defined and homogeneous sample of SNe and their edge-on host galaxies from the coverage of SDSS DR12, we analyse the vertical distributions and estimate the sech$^2$ and exp scale heights of the different types of SNe, associating them to the thick or thin disc populations of galaxies. Our sample consists of 100 nearby (the mean distance is 100 ± 8 Mpc), high-inclination ($i \geq 85^\circ$), and morphologically non-disturbed S0–Sd galaxies, hosting 102 SNe in total.

The extinction by dust near to the plane of edge-on host galaxies has an insignificant impact on our estimated SN scale heights, although as was shown previously (e.g. Paper I), it is significantly decreasing the efficiency of SN discovery in these galaxies. We also check that there is no strong redshift bias within our SNe and host galaxies samples, which could drive the observed behaviours of the vertical distributions of the both SN types in host galaxies with edge-on discs.

The results obtained in this article are summarized below, along with their interpretations.

(i) For the first time, we show that in both early- and late-type edge-on spiral galaxies the vertical distribution of CC SNe is about twice more concentrated to the plane of host disc than the distribution of Type Ia SNe (Fig. 4 and Table 2). The difference between the distributions of the SN types is statistically significant with only the exception in late-type hosts (Table 3).

(ii) When considering early- and late-type spiral galaxies separately, the vertical distributions of Type Ia and CC SNe are consistent with both the sech$^2$ and exp profiles (Table 2). In wider morphological bins (S0–Sa or Sa–Sd), the vertical distribution of Type Ia SNe is not consistent with sech$^2$ profile, most probably due to the earlier and wider morphological distribution of SNe Ia hosts galaxies in comparison with CC SNe hosts (Table 1), and the systematically thinner vertical distribution of the host stellar population from early- to late-type discs.

(iii) By narrowing the host morphologies to the most populated Sb–Sc galaxies (close to the MW morphology) of our sample, we exclude the morphological biasing of host galaxies between the SN types and the dependence of scale height of host stellar population on the morphological type. In these galaxies, we find that the sech$^2$ scale heights ($z_{\text{SN}}^2$) of Type Ia and CC SNe are 0.096±0.016 and 0.042±0.007, respectively. The exp scale heights ($H_{\text{SN}}$) are 0.065±0.012 and 0.028±0.003, respectively. In Sb–Sc galaxies, the vertical distribution of CC SNe is significantly different from that of Type Ia SNe (Table 3), being 2.3±0.5 times more concentrated to the plane of the host disc (Table 2).

(iv) In Sb–Sc hosts, the exp scale height (also the $h_{\text{SN}}/H_{\text{SN}}$ ratio) of CC SNe is consistent with that of the younger stellar population in the thin disc of the MW, derived from star counts, while the scale height (also the ratio) of SNe Ia is consistent with that of the old population in the thick disc of the MW (Tables 4 and 5).
These galaxies have lower masses than the MW.

Table 6. Comparison of the length to $\text{sech}^2$ height ratios of Type Ia and CC SNe in Sb–Sc galaxies
with those detected from resolved stars in nearby edge-on galaxies and from unresolved populations of extragalactic thick and thin discs.

| Host                        | $h/z_0$ | Reference       |
|-----------------------------|---------|-----------------|
| Edge-on Sc galaxies$^a$ (RGB-box) | 1.83 ± 0.99 | Seth et al. (2005) |
| SNe Ia (Sb–Sc)              | 2.08 ± 0.40 | This study      |
| Edge-on Sc galaxies$^a$ (AGB-box) | 2.40 ± 1.30 | Seth et al. (2005) |
| Edge-on galaxies$^b$ (thick+thin disc) | 2.67 ± 0.86 | Bizyaev et al. (2014) |
| Edge-on Sd galaxies$^c$ (thick disc) | 2.87 ± 0.72 | Yoachim & Dalcanton (2006) |
| Edge-on Sc galaxies$^a$ (MS-box) | 3.83 ± 1.79 | Seth et al. (2005) |
| SNe CC (Sb–Sc)              | 4.76 ± 0.93 | This study      |
| Edge-on Sd galaxies$^c$ (thin disc) | 5.48 ± 1.15 | Yoachim & Dalcanton (2006) |

Notes. For both the types of SNe, we use $h_{SN} = 0.20 ± 0.02$ (Paper III). The $h/z_0$ values are listed in ascending order.

$^a$The mean ratio of all six galaxies with the additional components of NGC 55 and NGC 4631 (from table 4 in Seth et al. 2005). These galaxies have lower masses than the MW.

$^b$To be consistent with the present study and the mentioned references, the mean ratio in $g$-band is estimated for a subsample of 529 galaxies from table 4 in Bizyaev et al. (2014) with bulge-to-total luminosity ratio (B/T) in $r$-band between 0.2 to 0.4 and distances $\leq$ 200 Mpc (a few galaxies, with obviously incorrect B/T values, are removed). The mean luminosity of this subsample ($\langle M_g \rangle = −20.9 ± 0.7$, corrected for Galactic extinction) is in good agreement with that of our Sb–Sc host galaxies ($\langle M_g \rangle = −20.5 ± 1.0$).

$^c$The mean ratio of all 34 galaxies in $R$-band from table 4 in Yoachim & Dalcanton (2006). These galaxies have lower kinematic masses than the MW.

(v) For the first time, we show that the ratio of scale lengths to scale heights ($h_{SS}/z_{SN}$) of the distribution of CC SNe is consistent with those of the resolved young stars with ages from $~10$ Myr up to $~100$ Myr in nearby edge-on galaxies and the unresolved stellar population of extragalactic thick discs (Table 6). On the other hand, the corresponding ratio for Type Ia SNe is consistent and located between the values of the same ratios of the two populations of resolved stars with ages from a few 100 Myr up to a few Gyr and from a few Gyr up to $~10$ Gyr, as well as with the unresolved population of the thick disc of nearby edge-on galaxies.

All these results can be explained considering the age-scale height relation of the distribution of stellar population and the mean age difference between Type Ia and CC SNe progenitors.

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