Constraining Type Ia supernovae via their distances from spiral arms

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ABSTRACT

We present an analysis of the distribution of 77 supernovae (SNe) Ia relative to spiral arms of their Sab–Scd host galaxies, using our original measurements of the SN distances from the nearby arms, and study their light curve decline rates ($\Delta m_{15}$). For the galaxies with prominent spiral arms, we show that the $\Delta m_{15}$ values of SNe Ia, which are located on the arms, are typically smaller (slower declining) than those of interarm SNe Ia (faster declining). We demonstrate that the SN Ia distances from the spiral arms and their galactocentric radii are correlated: before and after the average corotation radius, SNe Ia are located near the inner and outer edges (shock fronts) of spiral arms, respectively. For the first time, we find a significant correlation between the $\Delta m_{15}$ values and SN distances from the shock fronts of the arms (progenitor birthplace), which is explained in the frameworks of sub-Chandrasekhar-mass white dwarf explosion models and density wave theory, where, respectively, the $\Delta m_{15}$ parameter and SN distance from the shock front are appropriate progenitor population age (lifetime) indicators.

Key words: supernovae: individual: Type Ia – galaxies: spiral – galaxies: star formation – galaxies: stellar content.

1 INTRODUCTION

Type Ia supernovae (SNe Ia) are thought to be preceded by carbon-oxygen white dwarfs (WDs) in close binaries, while the characteristics of the progenitors and the explosion channels are still up for debate (e.g. Livio & Mazzali 2018). It is now evident that SNe Ia are not a homogeneous population of WD explosions, instead they exhibit photometric and spectroscopic diversities (e.g. Taubenberger 2017). One of the characteristic parameters of SNe Ia is the difference in $B$-band magnitudes between the max and 15 day, or the so-called SN light curve (LC) decline rate $\Delta m_{15}$, which is practically extinction-independent (e.g. Phillips et al. 1999). There is a correlation between this parameter and SN Ia luminosities at the maximum light: SNe Ia with larger $\Delta m_{15}$ values, or faster declining LCs, are fainter (Phillips 1993). The two most prevalent subclasses of peculiar SNe Ia are 91bg-like events, which are $\sim 2$ mag subluminous at the $B$-band maximum than normal SNe Ia and have fast-declining LCs, and 91T-like SNe, which are $\sim 0.6$ mag overluminous than normal ones and have slow-declining LCs (see Taubenberger 2017).

Theoretically, in sub-Chandrasekhar-mass (sub-$M_{\text{Ch}} \approx 1.4 M_{\odot}$) explosion models, the luminosity of SN Ia is closely proportional to the exploding WD’s mass (e.g. Sim et al. 2010; Blondin et al. 2017): WD in a double-degenerate system, which has mass lower than $M_{\text{Ch}}$, may, under appropriate circumstances, explodes as fainter SN Ia with faster declining LCs (Shen et al. 2017, 2021). Note that, in comparison to WD around the $M_{\text{Ch}}$ mass, WD with a lower mass comes from a main-sequence progenitor star with a lower mass and consequently with a longer lifetime (older progenitors).

From host galaxy studies, significant correlations are observed between SN Ia LC decline rate and the global ages of their hosts or local age at SN explosion sites (e.g. Gupta et al. 2011; Pan et al. 2014; Campbell et al. 2016; Rigault et al. 2020; Hakobyan et al. 2020, hereafter H20). On average, SNe Ia with larger $\Delta m_{15}$ values are associated with older stellar environments. On the other hand, important relationships between host stellar population and properties of SNe Ia progenitors can be found by looking at the distribution of SNe Ia relative to spiral arms of galaxies (e.g. Petroian et al. 2005; Aramyan et al. 2016, hereafter A16). It is worth noting that, according to the spiral density wave (DW) theory (Lin & Shu 1964; Roberts 1969), star formation (SF) typically occurs at shock fronts near the edges of spiral arms. From these regions, newly born SN progenitors move in the same direction as the disc rotation with respect to the spiral pattern until they reach their explosion sites (e.g. Mikhailova et al. 2007; A16). The distance from the spiral arm/progenitor birthplace is a potential indicator of SN Ia progenitor lifetime and thus can be used to constrain SN Ia progenitors. However, SN Ia LC decline rates have never been examined in SN studies based on where they are located on spiral arms or between, as well as $\Delta m_{15}$ as a function of the mentioned distance. In this Letter, we link the $\Delta m_{15}$ and SN Ia distributions relative to spiral arms of nearby host galaxies and demonstrate, for the first time, how this could provide another interesting way to study the properties of SN Ia progenitors.

2 SAMPLE SELECTION AND REDUCTION

The database of this study consists of SNe Ia from the sample of H20, after applying the restrictions described below. Note that H20 database is a compilation of 407 nearby SNe Ia ($z \lesssim 0.036$) with known spectroscopic subclasses and $B$-band LC decline rates ($\Delta m_{15}$). In addition, the database contains information on the distances of SNe Ia host galaxies, morphologies, $ugriz$ magnitudes,
and other parameters. For the current study, we selected only normal, 91T-, and 91bg-like SN Ia subclasses, which include a sufficient number of events from a statistical perspective.

For hosts, we restricted to Sab–Scd morphologies since we are interested in studying SNe Ia in galaxies with well-developed arms, where spiral DWs play an important role (e.g. Elmegreen & Elmegreen 1987; Pour-Imani et al. 2016; Karapetyan et al. 2018). Following the approach of Hakobyan et al. (2014), we visually checked the levels of morphological disturbances of the host galaxies using their images from different surveys. The hosts with interacting and merging attributes were excluded from the sample since we are interested in studying SNe Ia in non-disturbed spiral galaxies. In addition, to avoid projection and absorption effects in the discs due to high inclinations, as well as to accurately investigate the immediate vicinity of SNe Ia in terms of the existence of host spiral arms, the sample is limited to galaxies with $i < 60^\circ$. Only 142 SNe Ia in 137 host galaxies met the applied restrictions.

In spiral galaxies, the vast majority of SNe Ia belonging to normal, 91T-, and 91bg-like subclasses are discovered in disc of hosts (Hakobyan et al. 2021). Given this and using SN coordinates on the $g$-band images, for each SNe Ia we visually inspected the area of a circular ring in a quadrant of host disc, where the SN is discovered, in terms of presence of well-pronounced spiral arms. This is important because we aimed to link SN progenitors to a population of stars born due to the SF after passing and compressing gas clouds following A16, we normalized as those visually identified within the radius swept up by host galactic disc inclination (see Hakobyan et al. 2016, for details).

We determined the host spiral arm structures and the SNe positions with respect to the spiral arms according to the approaches detailed in A16. In short, we defined arm and interarm SNe Ia that are discovered inside the host arm edges or in the interarm region, respectively. To accomplish this, we used the residual images of the host galaxies after subtraction of the fitted $r^{1/4}$ bulge-exponential disc profiles from the smoothed $g$-band fits images. In the residual images, the values of the interarm pixels are negative, since the fitted profiles use fluxes from both the arm and interarm regions. Similar to A16, we fixed the edges of the spiral arms when the flux values change the sign. Fig. 1 shows examples of original and bulge+disc subtracted images of galaxies that host arm and interarm SNe Ia. Table A2 lists the numbers of SNe Ia in arm and interarm subsamples.

For each SNe Ia in the subtracted images, we measured the distance ($d$) from the $g$-band surface brightness peak of the nearest spiral arm through the galactocentric direction ($\Delta_\alpha$ distance in Fig. 2). Only for two cases (SN1997cw and SN2002ck), the interarm SN association with the nearest spiral arm is somewhat ambiguous. Following A16, we normalized $d$ to the corresponding distance of the spiral arm, i.e. $\tilde{d} = d/W_\Delta$, to compensate for the various linear sizes of the arm width in Fig. 2, with positive sign when the arm peak is between SN and the nucleus (see A16, for details).

It is worth noting that, according to the DW theory (e.g. Lin & Shu 1964; Roberts 1969), SF activities usually take place at a shock front around the inner edges of spiral arms inside the corotation radius ($R_C$), and around the outer edges of arms outside the corotation (see Fig. 2). For each SNe Ia, we also measured the distance ($D$) from the shock front of spiral arm through the galactocentric direction ($\Delta_\alpha$ and $\Delta_\delta$ distances in Fig. 2) inside and outside $R_C$, respectively). We normalized $D$ to the width ($W$) of the spiral arm ($\Delta_\alpha$ length in Fig. 2), i.e. $\tilde{D} = D/W$.

In addition, we estimated the deprojected galactocentric distances of SNe Ia ($R_{SN}$), using well-known approach of correction for the host galactic disc inclination (see Hakobyan et al. 2016, for details). This requires the offsets of SNe from the nucleus of host galaxies ($\Delta_\alpha$ and $\Delta_\delta$), the position angles and inclinations of the discs. Eventually, for each SNe Ia, the $R_{SN}$ is normalized to the $g$-band $R_{25}$, i.e. $\tilde{R}_{SN} = R_{SN}/R_{25}$, to compensate for the various linear sizes of hosts. Note that the mentioned parameters are not listed in H20, however they were compiled and/or estimated at the time of that study and are now available in the online database of this Letter.

Table A3 contains new database of this paper on all 77 individual SNe Ia (SN name, arm and interarm SN definition, $\tilde{d}$, $\tilde{D}$, $\tilde{R}_{SN}$), while H20 contains data on the spectroscopic subclasses and $B$-band $\Delta m_{15}$ of the events, as well as data on host galaxies.

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1 We used the FITS images from the Sloan Digital Sky Survey (SDSS; sdss.org), the SkyMapper (skymapper.anu.edu.au), and the Pan-STARRS (outerspace.stsci.edu/display/PANSTARRS) surveys.

2 $R_{25}$ is the $g$-band 25th magnitude isophotal semi-major axis of the disc.
3 RESULTS AND DISCUSSION

3.1 SNe Ia in arm and interarm regions of spiral galaxies

Fig. 3 presents the cumulative $\Delta m_{15}$ distributions of all sampled SNe Ia in arm and interarm regions. The inset in Fig. 3 shows the same distributions, but only for normal SNe Ia. To statistically compare the distributions, we use nonparametric methods (e.g. Engmann & Cousineau 2011): the two-sample Kolmogorov–Smirnov (KS) and Anderson–Darling (AD) tests. The $P$-values of the tests in Table 1 indicate that the two $\Delta m_{15}$ distributions, being compared for all sampled SNe Ia, are significantly different. For each SN Ia subclass, we also try to perform the same comparison. However, this can only be done for normal SNe Ia, while the numbers are insufficient for 91T- and 91bg-like events (see Table A2). As for all SNe Ia, the tests’ results show that the $\Delta m_{15}$ distributions of normal SNe Ia in arm and interarm regions are inconsistent significantly (with only barely AD test significance): the $\Delta m_{15}$ values of arm SNe Ia are, on average, smaller (slower declining LCs) in comparison with those of interarm SNe Ia (faster declining LCs).

The results presented above can be interpreted within the framework of the DW theory (e.g. Lin & Shu 1964; Roberts 1969) and WD explosion models with a sub-$M_{Ch}$ (Shen et al. 2017, 2021). According to the DW theory, stars (or SN Ia progenitors) were born around shock fronts of spiral arms (birthplace $e$ in Fig. 2) and migrate in the same direction as the disc rotation relative to the spiral pattern (travelled distance $e \delta$). In comparison with arm SNe Ia, interarm SNe Ia should have, on average, longer lifetime of their progenitors to travel from the birthplace through the entire arm and explode in interarm regions. Therefore, it can be assumed that interarm SNe Ia originates from an older progenitors than those in arm. The arm/interarm separation thus provides an effective way to distinguish, on average, between younger and older SN Ia progenitors.

On the other hand, as mentioned in the Introduction, in sub-$M_{Ch}$ explosion models (e.g. Sim et al. 2010; Blondin et al. 2017) the $\Delta m_{15}$ of SN Ia is correlated with the age of the progenitor system (larger $\Delta m_{15}$ values - older progenitors; Shen et al. 2017, 2021). The described link, together with what is indicated in the paragraph above, allows us to assume that interarm SNe Ia come, on average, from older stellar population with faster declining LCs in contrast to arm SNe Ia.

3.2 The distribution of SNe Ia relative to spiral arms

To supplement and develop the results obtained in the previous section, it is preferable to analyse continuous parameter distributions, such as the galactocentric radii of SNe and their distances from the host spiral arm, and relate them with SN LC decline rates rather than utilizing the arm and interarm discrete binning of SNe Ia.

In this context, a negative radial gradient of stellar population age seen in spiral discs (e.g. González Delgado et al. 2015) prompts us...
The relatively narrower is observed between the LC decline rate and the global ages of hosts (e.g. González Delgado et al. 2015). While a significant correlation from around 10 down to 8.5 Gyr from the center to the periphery this negative result by the observed fact that in stacked spiral discs rameters. In our recent study (Hakobyan et al. 2021), we explained significant correlation has been found (e.g. Gallagher et al. 2005; Sc Hubble 2005, see also Fig. 2). This is supported by the mentioned quantitative agreement for the average corotation radius of hosts and the observational fact that the SNe Ia explosion sites are mainly distributed around the inner and outer edges of the arms (shock fronts) inside and outside the corotation radius, respectively. Such locations of SNe Ia may be due to a combination of the circular velocity of progenitors in the disc relative to the pattern speed of the spiral arms (e.g. A16) and the ages of SN Ia progenitors (e.g. Childress et al. 2014). Long lived progenitors could travel farther by their circular orbits from the birthplaces around the shock fronts to the explosion sites. Inside the corotation radius this circular direction is from the inner to outer edges, while outside the corotation the direction is from the outer to inner edges of arms (e.g. es arcs in Fig 2). Given that spiral galaxies are outnumbered by short-lived (prompt, i.e. 200-500 Myr) SN Ia progenitors (e.g. Raskin et al. 2009; Childress et al. 2014), we observe their distribution close to their birthplaces around the shock fronts.

From the above described DW scenario, we can assume that the traveled circular distance of SN progenitor is an indicator of their age. On the other hand, from the es (esa) curvilinear triangle outside (inside) the corotation in Fig 2, it can be understood that the es (esa) distance is proportional to the es distance. Here, the sc (or sa) is the distance of SN Ia from the shock front of spiral arm through the galactocentric direction, which we measured in Section 2 and normalized to the arm width (i.e. D), while the es es is the traveled circular distance of SN progenitor.

Considering that SNe Ia LC decline rate can also be an age indicator for the progenitors in sub–MCs, explosion models, in Table 2 and Fig 5 we study the correlations between $\Delta m_{15}$ values and $\tilde{D}$ distances from the shock fronts of host spiral arms. The corresponding $P_{\text{sc}}$ values in Table 2 show that there are significant correlations between these parameters. The result ensures us to draw the conclusion that, on average, the progenitors of SNe Ia with smaller $\Delta m_{15}$ values have shorter lifetimes and thus traveled shorter distances from the shock fronts, i.e. birthplace, in contrast to progenitors with larger $\Delta m_{15}$ values, which have longer lifetimes and thus traveled farther away from the shock fronts.

The correlation tests in Table 2 show the positive trend between the $\Delta m_{15}$ of SNe Ia and their measured distances from the arm peak.

Table 2. Results of Spearman’s rank correlation tests for different continu-
parameters of SNe Ia.

| SN | $N_{\text{SN}}$ | $\Delta m_{15}$ versus $\tilde{r}_{\text{SN}}$ | $\rho_{\text{MC}}$ | $\rho_{\text{MC}}^+$ |
|----|----------------|----------------------------------|----------------|----------------|
| All | 77 | $\Delta m_{15}$ versus $\tilde{r}_{\text{SN}}$ | 0.032 | 0.783 |
| Normal | 67 | $\Delta m_{15}$ versus $\tilde{r}_{\text{SN}}$ | 0.021 | 0.867 |
| All | 77 | $d$ versus $\tilde{r}_{\text{SN}}$ | 0.330 | 0.003 |
| Normal | 67 | $d$ versus $\tilde{r}_{\text{SN}}$ | 0.370 | 0.002 |
| All | 77 | $\Delta m_{15}$ versus $D$ | 0.288 | 0.011 |
| Normal | 67 | $\Delta m_{15}$ versus $D$ | 0.280 | 0.022 |
| All | 77 | $\Delta m_{15}$ versus $d$ | 0.183 | 0.111 |
| Normal | 67 | $\Delta m_{15}$ versus $d$ | 0.077 | 0.360 |

Notes: Spearman’s coefficient ($-1 \leq \rho_{\text{MC}} \leq 1$) is a measure of rank correlation. The test’s null hypothesis is that the variables are independent, whereas the alternate hypothesis is that they are not. The permutations with $10^5$ MC iterations are used to generate the $\rho_{\text{MC}}$ values. Statistically significant correlations are marked in bold ($P \leq 0.05$).

![Figure 4](image-url) Distribution of the distances of SNe Ia relative to the peaks of spiral arms versus the deprojected and normalized galactocentric distance. The inner and outer edges (solid lines), as well the peak of spiral arm (dashed line) are shown by parallel lines. The best fits for all and normal SN subclass are presented by the solid- and dashed-thick lines, respectively. The error bars in the bottom-right corner display the typical measurement errors.

Figure 4 demonstrates that the dependency between the $\Delta m_{15}$ and $\tilde{r}_{\text{SN}}$ of SNe Ia. This dependency has been studied extensively in the past, but no significant correlation has been found (e.g. Gallagher et al. 2005; Sc Hubble 2005, see also Fig. 2). For different subsamples of our study, the Spearman’s rank test in Table 2 also shows not significant trends between the mentioned parameters. In our recent study (Hakobyan et al. 2021), we explained this negative result by the observed fact that in stacked spiral discs the azimuthally averaged stellar population age radially varies only from around 10 down to 8.5 Gyr from the center to the periphery (e.g. González Delgado et al. 2015). While a significant correlation is observed between the LC decline rate and the global ages of hosts (the ages range approximately from 1 to 10 Gyr, Gupta et al. 2011; Pan et al. 2014; Campbell et al. 2016; H20). The relatively narrower radial age range is most likely the reason why the $\Delta m_{15}$ versus $\tilde{r}_{\text{SN}}$ correlation cannot be well-observed.

However, we can uncover an important relationship between host stellar population and properties of SNe Ia progenitors by looking at the distribution of SNe Ia relative to spiral arms of galaxies (e.g. Petrosian et al. 2005; Mikhailova et al. 2007; A16). The relation between the normalized distances $d$ of SNe Ia from the arm peak and their deprojected and normalized galactocentric distances $\tilde{r}_{\text{SN}}$ are shown in Fig 4. There is a positive trend between the parameters, as shown by the fit line to the data. The Spearman’s rank correlation test in Table 2 indicates that this trend is statistically significant for all and normal SNe Ia samples. In A16, the corresponding trend was not significant, probably because of approximately 3.5 times smaller sample of SNe Ia and their different selection criteria for hosts and SN Ia subclasses.

In Fig 4, the fit line to the distances of SNe Ia relative to the arm peak intersects with the arm roughly at a value of 0.35 in units of isophotal radii. Since direct measurements of the corotation radii of host galaxies are not available for the current sample, we examine the averaged value of $R_C$ for seven host galaxies of SNe Ia from our previous paper Karapetyan et al. (2018). These galaxies’ averaged morphological type, Sbc, agrees well with that of the host galaxy sample used in the current study (Table A1). Moreover, the mean $R_C \approx 0.38 \pm 0.05$ for the mentioned sample from Karapetyan et al. is in good agreement with the intersection point in Fig 4. Therefore, this intersection point 0.35 can be adopted as an average corotation radius for our hosts in units of isophotal radii.

The findings in Fig 4 can be interpreted in the context of the DW theory where the steady waves in grand-design galaxies have a strong influence on triggering SF processes close to the shock fronts of spiral arms (e.g. Lin & Shu 1964; Roberts 1969, see also Fig. 2). This is supported by the mentioned quantitative agreement for the average corotation radius of hosts and the observational fact that the SNe Ia explosion sites are mainly distributed around the inner and outer edges of the arms (shock fronts) inside and outside the corotation radius, respectively. Such locations of SNe Ia may be due to a combination of the circular velocity of progenitors in the disc relative to the pattern speed of the spiral arms (e.g. A16) and the ages of SN Ia progenitors (e.g. Childress et al. 2014). Long lived progenitors could travel farther by their circular orbits from the birthplaces around the shock fronts to the explosion sites. Inside the corotation radius this circular direction is from the inner to outer edges, while outside the corotation the direction is from the outer to inner edges of arms (e.g. es arcs in Fig 2). Given that spiral galaxies are outnumbered by short-lived (prompt, i.e. 200-500 Myr) SN Ia progenitors (e.g. Raskin et al. 2009; Childress et al. 2014), we observe their distribution close to their birthplaces around the shock fronts.

From the above described DW scenario, we can assume that the traveled circular distance of SN progenitor is an indicator of their age. On the other hand, from the es (esa) curvilinear triangle outside (inside) the corotation in Fig 2, it can be understood that the sc (sa) distance is proportional to the es distance. Here, the sc (or sa) is the distance of SN Ia from the shock front of spiral arm through the galactocentric direction, which we measured in Section 2 and normalized to the arm width (i.e. $D$), while the es es is the traveled circular distance of SN progenitor.

Considering that SNe Ia LC decline rate can also be an age indicator for the progenitors in sub–MCs, explosion models, in Table 2 and Fig 5 we study the correlations between $\Delta m_{15}$ values and $\tilde{D}$ distances from the shock fronts of host spiral arms. The corresponding $P_{\text{sc}}$ values in Table 2 show that there are significant correlations between these parameters. The result enables us to draw the conclusion that, on average, the progenitors of SNe Ia with smaller $\Delta m_{15}$ values have shorter lifetimes and thus traveled shorter distances from the shock fronts, i.e. birthplace, in contrast to progenitors with larger $\Delta m_{15}$ values, which have longer lifetimes and thus traveled farther away from the shock fronts.

The correlation tests in Table 2 show the positive trend between the $\Delta m_{15}$ of SNe Ia and their measured distances from the arm peak,
which might be assumed from the result of the $\Delta m_{15}$ differences between SN Ia in arm/interarm regions. However, the $P_\text{t}$ values of the test show that this trend is not statistically significant. This significance likely caused by the blurs in $|\bar{d}|$ as a lifetime indicator in the distribution of $\Delta m_{15}$ versus $|\bar{d}|$, because the SN distance from the arm peak does not represent the progenitors’ traveled distance during entire lifetime (till to SN explosion): the spiral arm peak cannot be considered as a main birthplace of progenitors of SNe Ia.

It is worth noting that when conducting all statistical tests of our study without two SNe Ia with ambiguous association with the nearest spiral arm (see Section 2), all the results of the Letter and their significance remain unchanged.

4 CONCLUSIONS

In this Letter, using a sample of Sab–Scd galaxies hosting 77 SNe Ia and our measurements of the SN distances from the nearby spiral arms, we perform an analysis of the SNe distribution relative to host arms and study their LC decline rates ($\Delta m_{15}$). We demonstrate that the $\Delta m_{15}$ values of arm SNe Ia are typically smaller (slower declining) than those of interarm SNe Ia (faster declining). We show that the SN distances from the spiral arms and their galactocentric radii are correlated: before and after the average corotation radius, SNe Ia are located near the inner and outer edges (shock fronts) of spiral arms. For the first time, we find a correlation between $\Delta m_{15}$ values and the SN distances from the shock fronts of the arms. The results can be interpreted within the frameworks of DW theory, where SN progenitors were born around shock fronts of spiral arms and migrate crossing the spiral pattern to the explosion sites, and WD explosion models with sub-$M_{\text{Ch}}$, where SN LC decline rate is an indicator of progenitor age. On average, the progenitors of SNe Ia with smaller $\Delta m_{15}$ values have shorter lifetimes and thus traveled shorter distances from the shock fronts, i.e. birthplace, in contrast to progenitors with larger $\Delta m_{15}$ values, which have longer lifetimes and thus traveled farther away from the shock fronts.

As our study used a small sample size, we encourage new statistically more powerful studies with larger and more robust datasets of SNe Ia and their hosts (e.g. integral field observations, with available corotation radii) to better constrain the nature of SN Ia progenitor.

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DATA AVAILABILITY

The online version of this Letter contains the data underlying this study (see Table A3, for instructions).

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APPENDIX A: ONLINE MATERIAL

Table A1 shows morphological distribution of the sampled SNe Ia host galaxies, split between different SN subclasses. The numbers
Table A1. Morphological distribution of the sampled SNe Ia host galaxies, split between different SN subclasses.

| SN  | Sab | Sb | Sbc | Sc | Scd | All |
|-----|-----|----|-----|----|-----|-----|
| Normal | 6   | 18 | 25  | 17 | 1   | 67  |
| 91T  | 2   | 0  | 4   | 2  | 0   | 8   |
| 91bg | 2   | 0  | 0   | 0  | 0   | 2   |
| ALL  | 10  | 18 | 29  | 19 | 1   | 77  |

Table A2. Numbers of arm and interarm SNe Ia within Sab–Scd galaxies, split between different SN subclasses.

| SN  | arm | interarm |
|-----|-----|----------|
| Normal | 37  | 30       |
| 91T   | 6   | 2        |
| 91bg  | 0   | 2        |
| ALL   | 43  | 34       |

Table A3. The database of 77 SNe Ia of the study. The first ten entries are presented, while the entire table are available online.

| SN | Arm/interarm definition | \( \tilde{d} \) | \( \tilde{D} \) | \( \tilde{r}_{SN} \) |
|----|-------------------------|----------------|----------------|------------------|
| 1989A | interarm                  | 1.442          | 0.272          | 0.524            |
| 1989B | arm                      | 0.220          | 0.420          | 0.171            |
| 1990N | arm                      | 0.830          | 0.117          | 0.859            |
| 1990O | interarm                 | 1.753          | 0.541          | 0.764            |
| 1995al | arm                      | 0.516          | 0.601          | 0.302            |
| 1995E | arm                      | 0.478          | 0.398          | 0.411            |
| 1996ai | arm                      | 0.584          | 0.163          | 0.151            |
| 1996bo | arm                      | 0.445          | 0.537          | 0.122            |
| 1996Z  | interarm                 | 1.226          | 0.173          | 0.649            |
| 1997bp | interarm                 | 2.326          | 0.837          | 0.459            |

of arm and interarm SNe Ia within Sab–Scd galaxies are shown in Table A2.

Table A3 shows the first ten rows of the data used in our Letter. A CSV file containing the whole table is available online.