Supernovae Distribution and Host Galaxy Properties

A. A. Hakobyan, A. G. Karapetyan, L. V. Barkhudaryan, G. A. Mamon, D. Kunth, A. R. Petrosian, V. Adibekyan, L. S. Aramyan, and M. Turatto

1Byurakan Astrophysical Observatory, Byurakan, Armenia; hakobyan@bao.sci.am
2Institut d’Astrophysique de Paris, Paris, France;
3Instituto de Astrofísica e Ciência do Espaço, Porto, Portugal;
4Osservatorio Astronomico di Padova, Padova, Italy

Abstract. We present the summary of our last results on the spatial distribution and relative frequencies of Supernovae (SNe) in a large number of host galaxies from the Sloan Digital Sky Survey (SDSS). We use the locations of SNe in order to study the relations between radial/azimuthal distributions of SNe and properties of their hosts and environments. On the other hand, the vertical distribution of SNe allows to study the progenitors association to the thin or thick discs, and to the stellar halo. We also propose the underlying mechanisms shaping the number ratios of SNe types. It is important to note that there were no extended studies of the 3D distribution of SNe and structural parameters of hosts. Our study is intended to fill this gap and better constrain the nature of SN progenitors.

1. Introduction

A crucial aspect of many recent studies of extragalactic SNe is to establish the links between the nature of SN progenitors and stellar populations of their host galaxies. The most direct method for this is through their identification on pre-SN images. However, the number of such SNe is small and is limited to the nearby core-collapse (CC) events (e.g. Smartt 2009). These limitations force us to study the properties of SN progenitors through indirect methods.

The properties of SN host galaxies, such as the morphology, color, nuclear activity, star formation rate (SFR), metallicity, stellar population, age, etc. provide strong clues to the understanding of the progenitors (e.g. Mannucci et al. 2005; Petrosian et al. 2005; Hakobyan et al. 2008; Boissier & Prantzos 2009; Arcavi et al. 2010; Kelly & Kirshner 2012; Anderson et al. 2012, 2015; Aramyan et al. 2016). SN hosts in multiple systems of galaxies can also provide important constraints relating the star formation distribution/rate in strongly interacting systems with the different SN progenitors (e.g.

---

1SNe are generally divided into two categories according to their progenitors: CC and Type Ia SNe. CC SNe result from massive young stars that undergo CC (e.g. Turatto 2003; Anderson et al. 2012), while Type Ia SNe are the end point in the evolution of binary stars when an older white dwarf (WD) accretes material from its companion, causing the WD mass to exceed the Chandrasekhar limit, or a double WD system loses angular momentum due to gravitational wave emission, leading to coalescence and explosion (e.g. Maoz et al. 2014).
Anderson et al. 2011; Herrero-Illana et al. 2012). In particular, valuable information of the nature of progenitors can be obtained through the study of the radial (e.g. Hakobyan 2008; Förster & Schawinski 2008; Hakobyan et al. 2009; Kangas et al. 2013), azimuthal (e.g. Petrosian & Turatto 1995; Navasardyan et al. 2001), and vertical (e.g. Pavlyuk & Tsvetkov 2016) distributions of SNe and their environments (e.g. Leloudas et al. 2011; Galbany et al. 2016).

By this contribution, we present a brief summary of our results recently obtained in this field.

2. The database

Hakobyan et al. (2012) provides a large and well-defined database that combines extensive new measurements and a literature search of about four thousand SNe and their host galaxies located in the sky area covered by the SDSS Data Release 8. This database is much larger than previous ones, and provides a homogeneous set of global parameters of SN hosts, including measurements of apparent magnitudes, diameters, axial ratios, position angles, morphological classifications, and activity classes of nuclei. Special attention was paid to collect accurate data on the spectroscopic classes, coordinates, offsets of SNe, and heliocentric redshifts of the host galaxies. In Hakobyan et al. (2014), we also classified the morphological disturbances of nearby host galaxies from the visible signs of galaxy–galaxy interactions in the SDSS.2

All the presented results in the next section are mostly based on this database, which is publicly available.

3. Summary of our results

In this section, we list the results accompanied with short discussions. For more details, the reader is referred to Hakobyan et al. (2012, 2014, 2016); Nazaryan et al. (2013).

The number ratio of SN types

- The mean morphological type of spiral galaxies hosting Type Ia SNe is significantly earlier than the mean host type for all other types of CC SNe, which are consistent with one another.3

- We find a strong trend in the behaviour of \( N_{\text{Ia}}/N_{\text{CC}} \) depending on host-galaxy morphological type, such that early-type (high-mass or high-luminosity) spirals

---

2 The levels of disturbance are arranged in an approximate chronological order according to the different stages of interaction.

3 CC SNe are observationally classified in three major classes, according to the strength of lines in optical spectra (e.g. Filippenko 1997): Type II SNe show hydrogen lines in their spectra, including the IIn (dominated by emission lines with narrow components) and IIb (transitional objects with observed properties closer to SNe II at early times, then metamorphosing to SNe Ib) subclasses; Type Ib SNe show helium but not hydrogen, while Type Ic SNe show neither hydrogen nor helium. All these SNe types arise from young massive progenitors with possible differences in their masses, metallicities, ages, and fractions of binary stellar systems (e.g. Smith et al. 2011).
The distribution and host galaxy properties of SNe include proportionally more Type Ia SNe. The behaviour of $N_{\text{IA}}/N_{\text{CC}}$ versus morphology is a simple reflection of the behaviour of $1/sSFR$ versus morphological types of galaxies (e.g. Boissier & Prantzos 2009).

- The $N_{\text{IA}}/N_{\text{CC}}$ ratio is nearly constant when changing from normal, perturbed to interacting galaxies, then declines in merging galaxies, whereas it jumps to the highest value in post-merging/remnant host galaxies. During the relatively short time-scale of the merging stage (e.g. Lotz et al. 2008), the spiral, gas-rich galaxies do not have enough time to produce many Type Ia SNe, but can intensively produce CC SNe, assuming short lifetimes for the CC SNe progenitors. In the post-merging/remnant galaxies with longer time-scale, the SFRs and morphologies of host galaxies are strongly affected, significantly increasing the $N_{\text{IA}}/N_{\text{CC}}$ ratio.

- The $N_{\text{Ibc}}/N_{\text{II}}$ ratio is nearly constant when changing from normal, perturbed to interacting galaxies, then jumps to the highest value in merging galaxies and slightly declines in post-merging/remnant subsample. In our merging hosts, the positions of CC SNe, particularly SNe of Ibc type, mostly coincide with the circumnuclear regions and only in few cases with bright H II regions, which is in agreement with the previously found central excess of CC SNe in extremely disturbed or merging galaxies (e.g. Habergham et al. 2012; Herrero-Illana et al. 2012).

- Type Ibc SNe are located in pairs of galaxies with significantly smaller difference of radial velocities between components than pairs containing Types Ia and II SNe. We consider this as a result of higher SFR of these closer systems of galaxies (e.g. Patton et al. 2011). SN types are not correlated with the luminosity ratio of host and neighbor galaxies in pairs.

- The $N_{\text{IA}}/N_{\text{CC}}$ ($N_{\text{Ibc}}/N_{\text{II}}$) ratio increases (decreases) when moving from SF, C, to Sy+LINER activity classes for the host galaxies. In the invoked scenario, the interaction is responsible for morphological disturbances and for partially sending gas inward, which first triggers star formation (e.g. Sabater et al. 2013) and increases sSFR (e.g. Lotz et al. 2008). Therefore, in the SF stage, we observe a lower value of the $N_{\text{IA}}/N_{\text{CC}}$ ratio and a somewhat higher value of the $N_{\text{Ibc}}/N_{\text{II}}$ ratio as in morphologically disturbed (interacting or merging) late-type galaxies. The starburst then fades with time and the C (composite of SF and AGN) class evolves to the AGN [Sy+LINER] (e.g. Wild et al. 2010) with a comparatively relaxed disturbance, early-type morphology, poor gas fraction, and old stellar population. Therefore, in the AGN stage, we observe inverse values of the ratios as in morphologically less disturbed (relaxed) early-type galaxies.

The radial distribution of SNe

- In Sa–Sm galaxies, all CC and the vast majority of Type Ia SNe belong to the disc, rather than the bulge component. This result suggests that the rate of SNe
Ia in spiral galaxies is dominated by a relatively young/intermediate progenitor population (e.g. Mannucci et al. 2005; Hakobyan et al. 2011; Li et al. 2011).

- The radial distribution of Type Ia SNe in S0–S0/a galaxies is inconsistent with that in Sa–Sm hosts. This inconsistency is mostly attributed to the contribution by SNe Ia in the outer bulges of S0–S0/a galaxies. In these hosts, the relative fraction of bulge to disc SNe Ia is probably changed in comparison with that in Sa–Sm hosts, because the progenitor population from the discs of S0–S0/a galaxies should be much lower due to the lower number of young/intermediate stellar populations.

- The radial distribution of CC SNe in barred Sa–Sbc galaxies is not consistent with that of unbarred Sa–Sbc hosts, while for Type Ia SNe the distributions are not significantly different. At the same time, the radial distributions of both Type Ia and CC SNe in Sc–Sm galaxies are not affected by bars. These results are explained by a substantial suppression of massive star formation in the radial range swept by strong bars of early-type barred galaxies (e.g. James et al. 2009; James & Percival 2015).

- The radial distribution of CC SNe, in contrast to Type Ia SNe, is inconsistent with the exponential surface density profile, because of the central \((R_{SN}/R_{25} < 0.2)\) deficit of SNe. However, in the \(R_{SN}/R_{25} \in [0.2; \infty)\) range, the inconsistency vanishes for CC SNe in most of the subsamples of spiral galaxies. In the inner-truncated disc, only the radial distribution of CC SNe in barred early-type spirals is inconsistent with an exponential surface density profile, which appears to be caused by the impact of bars on the radial distribution of CC SNe.

- In the inner regions of non-disturbed spiral hosts, we do not detect a relative deficiency of Type Ia SNe with respect to CC, contrary to what was found by other authors (e.g. Wang et al. 1997; Anderson et al. 2015), who had explained this by possibly stronger dust extinction for Type Ia than for CC SNe. Instead, the radial distributions of both types of SNe are similar in all the subsamples of Sa–Sbc and Sc–Sm galaxies, which supports the idea that the relative increase of CC SNe in the inner regions of spirals found by the other authors is most probably due to the central excess of CC SNe in disturbed galaxies (e.g. Habergham et al. 2012; Herrero-Illana et al. 2012).

**The azimuthal and vertical distributions of SNe**

- The orientation of SNe in host with respect to the preferred direction toward neighbor galaxy is found to be isotropic and independent of kinematical properties of the galaxy pair.

- The vertical distribution of CC SNe is significantly different from that of Type Ia SNe, being about twice more concentrated to the plane of the disc in edge-on host galaxies. The vertical distribution of CC SNe can be assigned to the younger thin disc population, while the distribution of Type Ia SNe is consistent with the older thick disc of edge-on galaxies.

---

\(^6\) The \(R_{25}\) is the SDSS g-band 25th magnitude isophotal semimajor axis of SN host galaxy.
The obtained results show that the spatial distributions and the number ratios of different SNe are powerful tools to constrain the natures of their progenitors and to better understand the star formation processes in various types of galaxies.

Acknowledgments. This work was supported by the RA MES State Committee of Science, in the frames of the research project number 15T–C129. This work was made possible in part by a research grant from the Armenian National Science and Education Fund (ANSEF) based in New York, USA. V.A. acknowledges the support from FCT through Investigador FCT contracts of reference IF/00650/2015. V.A. also acknowledges the support from Fundação para a Ciência e Tecnologia (FCT) through national funds and from FEDER through COMPETE2020 by the following grants UID/FIS/04434/2013 & POCI-01-0145-FEDER-007672, PTDC/FIS-AST/7073/2014 & POCI-01-0145-FEDER-016880 and PTDC/FIS-AST/1526/2014 & POCI-01-0145-FEDER-016886.

References

Anderson, J. P., Habergham, S. M., James, P. A. 2011, MNRAS, 416, 567
Anderson, J. P., Habergham, S. M., James, P. A., Hamuy, M. 2012, MNRAS, 424, 1372
Anderson, J. P., James, P. A., Förster, F., et al. 2015, MNRAS, 448, 732
Aramyan, L. S., Hakobyan, A. A., Petrosian, A. R., et al. 2016, MNRAS, 459, 3130
Arcavi, I., Gal-Yam, A., Kasliwal, M. M., et al. 2010, ApJ, 721, 777
Boissier, S., Prantzos, N. 2009, A&A, 503, 137
Filippenko, A. V. 1997, ARA&A, 35, 309
Förster, F., Schawinski, K. 2008, MNRAS, 388, L74
Galbany, L., Stanishev, V., Mourão, A. M., et al. 2016, A&A, 591, A48
Habergham, S. M., James, P. A., Anderson, J. P. 2012, MNRAS, 424, 2841
Hakobyan, A. A. 2008, Astrophysics, 51, 69
Hakobyan, A. A., Adibekyan, V. Z., Aramyan, L. S., et al. 2012, A&A, 544, A81
Hakobyan, A. A., Karapetyan, A. G., Barkhudaryan, L. V., et al. 2016, MNRAS, 456, 2848
Hakobyan, A. A., Mamon, G. A., Petrosian, A. R., et al. 2009, A&A, 508, 1259
Hakobyan, A. A., Nazaryan, T. A., Adibekyan, V. Z., et al. 2014, MNRAS, 444, 2428
Hakobyan, A. A., Petrosian, A. R., Mamon, G. A., et al. 2011, Astrophysics, 54, 301
Hakobyan, A. A., Petrosian, A. R., McLean, B., et al. 2008, A&A, 488, 523
Herrero-Illana, R., Pérez-Torres, M. Á., Alberdi, A. 2012, A&A, 540, L5
James, P. A., Bretherton, C. F., Knapen, J. H. 2009, A&A, 501, 207
James, P. A., Percival, S. M. 2015, MNRAS, 450, 3503
Kangas, T., Mattila, S., Kankare, E., et al. 2013, MNRAS, 436, 3464
Kelly, P. L., Kirshner, R. P. 2012, ApJ, 759, 107
Leloudas, G., Gallazzi, A., Sollerman, J., et al. 2011, A&A, 530, A95
Li, W., Chornock, R., Leaman, J., et al. 2011, MNRAS, 412, 1473
Lotz, J. M., Jonsson, P., Cox, T. J., Primack, J. R. 2008, MNRAS, 391, 1137
Mannucci, F., Della Valle, M., Panagia, N., et al. 2005, A&A, 433, 807
Maoz, D., Mannucci, F., Nelemans, G. 2014, ARA&A, 52, 107
Navasardyan, H., Petrosian, A. R., Turatto, M., et al. 2001, MNRAS, 328, 1181
Nazaryan, T. A., Petrosian, A. R., Hakobyan, A. A., et al. 2013, Ap&SS, 347, 365
Patterson, D. R., Ellison, S. L., Simard, L., et al. 2011, MNRAS, 412, 591
Pavluk, N. N., Tsvetkov, D. Y. 2016, Astronomy Letters, 42, 495
Petrosian, A., Navasardyan, H., Cappellaro, E., et al. 2005, AJ, 129, 1369
Petrosian, A. R., Turatto, M. 1995, A&A, 297, 49
Sabater, J., Best, P. N., Argudo-Fernández, M. 2013, MNRAS, 430, 638
Smartt, S. J. 2009, ARA&A, 47, 63
Smith, N., Li, W., Filippenko, A. V., Chornock, R. 2011, MNRAS, 412, 1522
Turatto, M. 2003, Supernovae and Gamma-Ray Bursters, 598, 21
Wang, L., Höflich, P., Wheeler, J. C. 1997, ApJ, 483, L29
Wild, V., Heckman, T., Charlot, S. 2010, MNRAS, 405, 933