Binary Paths to Type Ia Supernovae Explosions
Proceedings IAU Symposium No. 281, 2011
R. Di Stefano, M. Orio, & M. Moe, eds.

doi:10.1017/S1743921312014597

"Pure" Supernovae and Dark Energy

M. V. Pruzhinskaya, E. S. Gorbovskoy, and V. M. Lipunov

Sternberg Astronomical Institute, Lomonosov Moscow State University,
Universitetskii pr. 13, Moscow, 119992 Russia
email: pruzhinskaya@gmail.com

Abstract. A special class of Type Ia supernovae that is not subject to ordinary and additional intragalactic gray absorption and chemical evolution has been identified. Analysis of the Hubble diagrams constructed for these supernovae confirms the accelerated expansion of the Universe irrespective of the chemical evolution and possible gray absorption in galaxies.

Keywords. supernovae: general — cosmological parameters

1. Introduction

Type Ia supernovae (SNe Ia), the thermonuclear explosions of accreting white dwarfs, are the most precise distance indicators at cosmological scales. Even though they are not standard candles, their absolute magnitudes at maximum light are closely correlated with the shape of their light curves. This correlation was first discovered by Pskovskii (1977). As precise standardizable candles they have been used to trace the expansion of the universe as a function of redshift, leading to the discovery of the accelerated expansion.

However, despite the present day light curve standardization methods, there are doubts of the validity of the 'standard-candle' hypothesis. First, the so-called gray dust, whose absorption is wavelength independent and essentially cannot be taken into account (Bogomazov & Tutukov 2011), could lead to the dimming of distant supernovae. This can be large dust particles with typical sizes greater than 0.01 μm (Aguirre 1999). In addition, it is possible that SNe Ia explosions can depend on the chemical composition of the stellar progenitors. The further into the Universe we look, the earlier in a chemical sense the stellar population we see. Moreover, there are two mechanisms of explosion of SNe Ia: the double degenerate (DD) mechanism (Iben & Tutukov 1984, Webbink 1984) and the single degenerate (SD) mechanism (Whelan & Iben 1973). The DD mechanism is the merging of two white dwarfs (WDs), while the SNe Ia explosion via the SD mechanism is a result of matter accretion onto the WD from a stellar binary companion.

The recent discovery of ultraluminous SNe Ia (Nugent *et al.* 2010) confirms the existing spread in supernova luminosities at maximum. The existence of such objects is quite predictable within the model of merging WDs, the sum of whose masses is not constant and changes slowly with the Hubble time of the Universe. The point is that the mergers of, on average, more massive WDs than those at present occurred at the early evolutionary stages of the Universe. According to Tutukov's calculations (Bogomazov & Tutukov 2011), the mean energy of SNe Ia must grow with $z > 2$ and increase significantly at $z > 8$.

To exclude the possible influence of the three factors: absorption, chemical evolution of stellar progenitors, and differences in explosion mechanisms, we suggest to use a special class of Type Ia supernovae - 'pure' supernovae.

2. Selection Method

The main idea of our method is to use only the supernovae that are located in elliptical (E) galaxies or far from the center of host spiral galaxies. The oldest, metal-poor stars with an age comparable to that of the Universe lie at great distances from the nucleus (or high above the plane if we are dealing with an edge on spiral host galaxy). This automatically leads to a more homogeneous chemical composition of the progenitor stars.

'Pure' SNe Ia are not influenced by either the usual absorption, or by additional intragalactic gray absorption, because they exploded in E galaxies or far from the center of a spiral galaxy. There is no dust in spiral galaxies' halos. For example, in our Galaxy the dust layer thickness is less than a few kpc, even at the edges [15-20 kpc]. In the E galaxies, there is no dust, even deep within the galaxy.

Moreover 'pure' SNe Ia are very likely to have a common explosion mechanism: the merging of two WDs. This is due to the fact that in spiral galaxies' halos there are no stars that can provide the needed rate of accretion on a white dwarf in binary system. Recall that the Schatzman (or SD) mechanism (Whelan & Iben 1973) suggests the accumulation of mass by a white dwarf up to the Chandrasekhar limit in binary systems with accretion rate of more than $10^{-8} - 10^{-7}$ $M_\odot$ yr^{-1}. This is due to the fact that there are no intermediate-mass stars in the galaxy halos that could provide the accumulation of matter by white dwarfs in binary systems. In contrast, the white dwarf merger mechanism in elliptical galaxies provides up to 99% of SNe Ia explosions. The very first evolutionary computations of such processes in elliptical galaxies (population synthesis) performed using a special computer code - the Scenario Machine (Lipunov *et al.* 1996, Lipunov *et al.* 2009)- showed that the mechanism of white dwarf mergers outperforms accretion by two order of magnitude already one billion years after the formation of the elliptical galaxy (Jogensen *et al.* 1997). The study of supernovae in recent years allowed the evolution of the supernova rates in elliptical galaxies to be observed for the first time (Totani *et al.* 2008, Mannuci *et al.* 2005). The observational data are in excellent agreement with the supernova rates predicted by the theory of evolution of binary stars (Lipunov, Panchenko, & Pruzhinskaya 2011, see Figure 1).

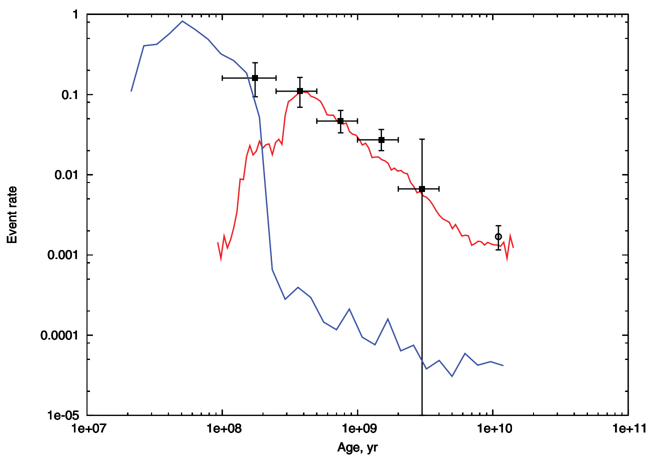

Figure 1. The theoretical prediction of the SNe Ia rate (yr^{-1}) evolution in a sample elliptical galaxy of 10^{11} $M_\odot$ after an instantaneous burst of star formation (Jogensen *et al.* 1997). The filled squares are the observational points (Totani *et al.* 2008). The open circle is observational SNe Ia rate in elliptical galaxies in the local Universe (Mannuci *et al.* 2005).

https://doi.org/10.1017/S1743921312014597 Published online by Cambridge University Press

For our work, we used the supernovae from Hicken *et al.* (2009) and Kowalski *et al.* (2008). In the first step, from all supernovae we chose those that were far beyond the host galaxy. The distance from the galaxy center in units of D25 for the galaxy (i.e., the photometric size of the isophote with a magnitude of 25 per square arcmin in the B band) served as a quantitative criterion. If the distance exceeded D25, then the supernova was considered distant. After an examination of the compiled list, we eliminated the questionable cases of spiral and interacting galaxies where it was generally difficult to draw the boundary of the host galaxy. In addition to the supernovae far from the galaxy center, we selected the supernovae whose host galaxies were confidently classified as elliptical ones. We then examined the objects discovered by the Hubble Space Telescope (Riess *et al.* 2004, Riess *et al.* 2007) at great distances ($z > 0.2$). Here, the sample was produced visually. Two halo supernovae, SN2008gy (Tsvetkov *et al.* 2010) and SN2009nr (Khan *et al.* 2010, Tsvetkov *et al.* 2011), discovered in the survey of the MASTER robotized network were added to them. Note that SN2008gy and SN2009nr are the first most thoroughly investigated nearby supernovae that are essentially located in intergalactic space. Thus, a list of supernovae ready for the construction of Hubble diagrams appeared. These SNe Ia were plotted on the Hubble diagram (see Figure 2).

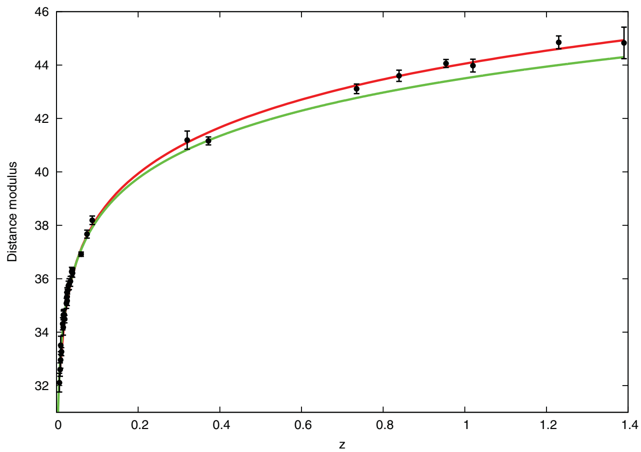

Figure 2. Hubble diagram for SNe Ia constructed from the points from the list. The red (darker) curve is the best fit to the observational data. The green curve corresponds to the Universe without dark energy.

The slope of the Hubble diagram shows the presence of dark energy, accelerated expansion of the Universe, even for those supernovae that exploded in the regions where the absorption (including the gray one) is minimal! According to these data, the Universe is expanding with $\Omega_\Lambda = 0.66 \pm 0.18$.

To answer the question of whether the class of SNe Ia under consideration differs from all of the remaining SNe Ia, we considered the supernovae up to $z < 0.06$. We note that the variance for 'pure' supernovae is considerably lower than that for all supernovae. For example, the mean squared error in magnitudes for pure supernovae is 0.04, while it is 0.2 for the remaining supernovae from Hicken *et al.* (2009) and Kowalski *et al.* (2008).

3. Conclusions

In regards to the 'standard' nature of SNe Ia, more and more questions arise with every year. Several SNe Ia explosion mechanisms have been found to exist. The brightness of supernovae can change depending on the mechanism being realized. It is also quite possible that the SNe Ia explosion can depend on the chemical composition of the progenitor star. Here, we considered the question of whether the brightness becomes nonstandard due to the absorption of light by gray dust in the host galaxies. According to the gray absorption hypothesis, the accelerated darkening of supernovae is attributable primarily to the absorption of light by gray dust whose influence is not yet taken into account by the standard procedures of allowance for the absorption. In addition, the amount of gray dust was greater in the past. To investigate this effect, we considered the supernovae exploded far from the host galaxy center where there is little gas and dust, including gray one. The result obtained shows accelerated expansion of the Universe and the presence of dark energy at a level of $\Omega_\Lambda = 0.66 \pm 0.18$. The difference between the curve corresponding to the Universe without dark energy and the curve fitting the 'pure' supernovae on the Hubble diagram is 1^m. This value will increase if we take into account the fact that the supernovae were brighter in the past due to the larger mass of the merging white dwarfs. There is reason to believe that the class of supernovae considered is more homogeneous. These stars exploded in elliptical galaxies or far from the center of their host galaxies. Consequently, the supernova progenitors had a similar chemical composition. The mechanism for the explosion of pure supernovae is the merger of two white dwarfs. Therefore, they show a smoother behavior on the Hubble diagram than all of the remaining SNe Ia.

The main result of our analysis is the confirmation of accelerated expansion of the Universe irrespective of the chemical evolution and possible gray absorption. The class of pure supernovae we identified can be an efficient tool for investigating the properties of the accelerated expansion of the Universe.

The work was supported by the Ministry of Science of the Russian Federation (state contract No.02.740.11.0249) and the non-profit Dynasty Foundation.

References

Aguirre, A. 1999, *ApJ*, 512, 19

Bogomazov, A. I. & Tutukov, A. V. 2011, *Astron. Rep.*, 55, 497

Hicken, M., Wood-Vasey, W., & Blondin, S., *et al.* 2009, *ApJ* 700, 1097

Iben, I. & Tutukov, A. V. 1984, *ApJS*, 54, 335

Jorgensen, H. E., Lipunov, V. M., Panchenko, I. E., Postnov, K. A., & Prokhorov, M. E. 1997, *ApJ*, 486, 110

Khan, R., *et al.* 2010, *arXiv:1008.4126v3*

Kowalski, M., Rubin, D., & Aldering, G., *et al.* 2008, *ApJ*, 686, 749

Lipunov, V. M., Panchenko, I. E., & Pruzhinskaya, M. V. 2011, *New Astron.*, 16, 250

Lipunov, V. M., Postnov, K. A., & Prokhorov, M. E. 1996, *Astrophysics and Space Physics Reviews*, 17

Lipunov, V. M., Postnov, K. A., Prokhorov, M. E., & Bogomazov, A. I. 2009, *Astron. Rep.*, 53, 915

Mannucci, F., *et al.* 2005, *A&A*, 433, 807

Nugent, P., Howell, D. A., & Sullivan, M., *et al.* 2010, *Astron. Telegram.*, No. 2917

Pskovskii, Yu.P. 1977 *Soviet Astronomy*, 21, 675

Riess, A. G., Strolger, L.-G., & Tonry, J., *et al.* 2004, *ApJ*, 607, 665

Riess, A. G., Strolger, L.-G., & Casertano, S., *et al.* 2007, *ApJ*, 659, 98

Totani, T., Morokuma, T., & Oda, T., *et al.* 2008, *PASJ*, 60, 1327

Tsvetkov, D. Y.u., Balanutsa, P. V., & Gorbovskoy, E. S., *et al.* 2010, *Perem. Zvezdy*, 30, 3

Tsvetkov, Yu.D., *et al.* 2011, *PAZ*, 37, 823

Webbink, R. 1984, *ApJ*, 277, 355

Whelan, J. & Iben, I. 1973, *ApJ*, 186, 1007