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Local Supernovae ⋆

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Abstract. Despite the vast interest on Supernovae and that their sources of energy have been known for decades, our understanding of the physics of Supernova explosions is far from being satisfactory. While SNe can shed light on the geometry and content of the whole Universe, the mechanisms of their explosions can be understood only through the detailed study of local SNe. In this paper I briefly address some recent progresses in this field of research obtained with intensive studies of nearby objects.

Key words. Supernovae

1. Introduction

For their use in Cosmology and their possible connection to Gamma–Ray Bursts Supernovae (SNe) have gained over the past few years the stage of Astronomy. However, even before these recent performances the SNe were already considered crucial players in driving the chemical evolution of galaxies, in testing the stellar evolutionary theories and in providing the energy of the Interstellar Medium.

Despite of this, many of the properties of SNe remain largely uncertain and our understanding of the underlying physics is far from being satisfactory. For instance, it is clear that only once we will comprehend the processes driving the thermonuclear explosions of type Ia, we will be able to constrain systematic errors in the determination of cosmological parameters and to rule out possible evolutionary effects on the progenitor populations such as the IMF and the metallicity (Höflich et al. 1997).

It is evident that major advances toward the comprehension of the complex physical processes taking place inside the SNe can be done only through the detailed observations of specimens exploding in the local Universe. No surprise therefore if in parallel to the surveys of high–z SNe also new, large projects on nearby SNe have recently flourished.

⋆ Partially based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Centro Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias (prop. AO7-TAC-48) and on observations collected at the European Southern Observatory (prop. ESO 63.H-0141 and 66.D-0683)

2. SN taxonomy

Unfortunately, but unavoidably, when pushing for a more accurate description of any phenomenon, new, unexpected complications arise. This is the case of the taxonomical classification of SNe which is usually performed by means of optical spectra. Since early spectra consist of thermal continua with overimposed P-Cygni profiles of lines formed by resonant scattering, it is clear that SN types are assigned on the basis of the chemical and physical properties of the outermost layers of the exploding stars.

Historically SNe have been divided into two main classes (Minkowski 1941) on the basis of the presence or absence of hydrogen lines in their spectra: SNe of type I (SNI) did not show H lines, while those with the obvious presence of H were called type II (SNII). Type I SNe were characterized by a deep absorption at 6150 Å which was not present in the spectra of some objects, therefore considered peculiar.

In the mid-1980s, evidence began to accumulate that the peculiar SNI formed a class physically distinct from the others. These objects, characterized by the presence of HeI (Gaskell et al. 1986; Harkness et al. 1987), were called type Ib (SNIb), and "classical" SNI were renamed as type Ia (SNIa). The new class further branched into another variety, SNIc, based on the absence of He I lines. Whether these are physically distinct types of objects has been long debated (Harkness & Wheeler 1990).

Type II were soon recognized as very heterogeneous (Barbon et al. 1979). Four subclasses of SNII are commonly mentioned in the literature: IIP, IIL, IIn and IIb, but a number of peculiar objects do not fit into any of these categories. Of particular interest are SNIIb, a class of few objects having early time spectra similar to type II (i.e. with prominent H lines) and late time spectra similar to type Ib/c. These transforming SNe constitute the previously missing link between SNIb/c and massive stars.

From what said above descends that, despite the misleading nomenclature determined by historical reasons, we currently divide SNe into two major classes of explosions: *a)* that constituted only by SNIa whose overall homogeneous spectroscopic and photometric behavior has led to a general consensus that they are associated with the thermonuclear explosions of white dwarfs; *b)* core-collapse explosions of massive stars, which include all kinds of SNII and the SNIb/c. A general scenario has been proposed in which the sequence of types IIP-IIL-IIb-Ib-Ic is ordered according to a decreasing mass of the envelope of the progenitor at the explosion (Nomoto et al. 1995).

Late time spectra confirm the physical similarity between SNIb/c and SNII. Indeed a few months after the explosion the entire ejecta become transparent and also the innermost material synthesized during the explosion become visible. At such stage the spectra of SNIb/c display strong lines of [OI], [CaII], MgI] resulting remarkably similar to those of SNII, with the only noticeable exception of Hα.

An extensive review on the SN taxonomy can be found in (Turatto 2003).

3. Local thermonuclear

At the beginning of the '90s, with the improvement of the signal–to–noise of the observations, it was finally demonstrated that differences exist also among SNIa both as light curve shape and luminosity. Fortunately empirical relations have been found between these two quantities. These relations have allowed to recover the SNIa as accurate distance indicators but need large samples of nearby, reliable templates to design the functional dependence and a precise calibration. Indeed, thanks to new and better samples available in the last decade several revisions of these relations have been published (Phillips 1993;

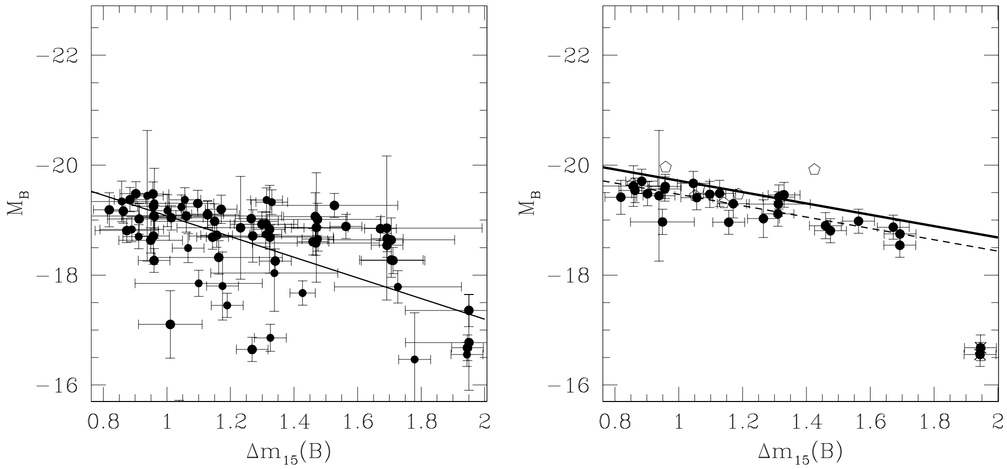

Fig. 1. M_B versus Δm_{15} relation for SNIa . Left: 73 well studied, nearby objects are included with distance from several sources and reported to the $H_o = 75$ km s^{-1} Mpc^{-1} scale. Right: the sample has been first corrected for the total reddening according to Phillips et al (1999) and limited only to all SNIa with E(B–V)<0.1 and small errors on Δm_{15}. Then a linear fit not including subluminous events (1991bg-like) events has been performed (dashed line). The final relation (continuous line) has been obtained by shifting the regression line above to match the Cepheid calibrated SNIa (open symbols) with the metallicity correction from the HST Key Project (cfr. Altavilla et al. 2003).

Phillips et al. 1999; Riess et al. 1996, 1998).

HST has allowed the precise determination of the distances of a number of parent galaxies of SNIa through the Cepheids. Clearly any indetermination on the Cepheid calibration reflects also on the eventual determination of H_o obtained with the SNIa. In order to determine how different Period–Luminosity calibrations of the Cepheids affect the value of H_o, Altavilla et al. (2003) have independently analyzed of the data of the best studied, nearby SNIa. Figure 1 summarizes the procedure followed. They have first verified the linearity of the peak luminosity vs. light curve shape relation (for all SNIa but the subluminous SN1991bg–like type Ia). Then they have calibrated such relation by mean of Cepheids–calibrated SNIa.

They concluded that different Cepheid calibrations have a small impact on the final value H_o while a major role is played by the extinction correction, suggesting also that the dust properties in the parent galaxies of SNIa might not be the same.

Among the possible causes of the observed photometrical diversity of SNIa are different masses of the progenitor WD or different opacities in Chandrasekhar–mass explosions. Indeed analytical studies (Arnett 1982, 1996) have shown that the brightness at maximum is proportional to the mass of synthesized ^{56}Ni and the width of the light curve depends on the mass of the ejecta, the kinetic energy of the explosion and the opacity. Nevertheless, a detailed comprehension of the SNIa diversity is still missing and we emphasize that the relations discussed above are purely empirical.

In analogy to the photometric sequence above Nugent et al. (1995) have presented evidence for a spectroscopic sequence which correlates the ratio of the depth of the SiII 5972λ and 6355λ absorption troughs to the speed of decline (and therefore to the luminosity). They provided also a partial theoretical explanation for the sequence on the basis of synthetic spectra and attributed the differences in the emerging spectra mainly to variations in the effective temperatures.

A recent reanalysis has shown that while the relation holds for $\Delta m_{15} \geq 1.2$, at smaller values the Nugent et al. relation breaks down (Benetti et al. 2003). Moreover, the ratio between the intensity of the two SiII lines undergoes a dramatic evolution before maximum light with completely different trends for various objects.

The picture of a one–parameter sequence in the properties of SNIa has further complicated recently. On one side two dramatical peculiar SNIa have ben discovered, SNe 2000cx and 2002cx. These two objects do not fit into any photometric and spectroscopic sequence still showing the main characteristics of type Ia SNe (Li et al. 2001, 2003). On the other, evidence has accumulated that also normal SNIa with similar light curves might show very different spectral features at specific epochs. An example of this is shown in Figure 2 in which the spectra of four objects about one week before B maximum are compared. While SN 2000E is very similar to SN 1990N, which has a different Δm_{15}, it shows noticeable difference with respect the two SNe at the bottom, having exactly the same decline rates. In particular, the overall appearance of SN 1991T at this phase differs from others; it is dominated by FeIII lines and does not show the characteristic lines of intermediate mass elements, e.g. SiII 6355 λ. In addition even among the three SNe at the top the profiles of SiII 6355λ, i.e. the velocity distributions of SiII above the photosphere, are definitely different and the SiII 4130λ, sometimes used to classify high redshift SNe as SNIa, is illdefined in SN 1999ee. In general, several other less pronounced features indicating differences in the physical conditions and chemical structures, are present.

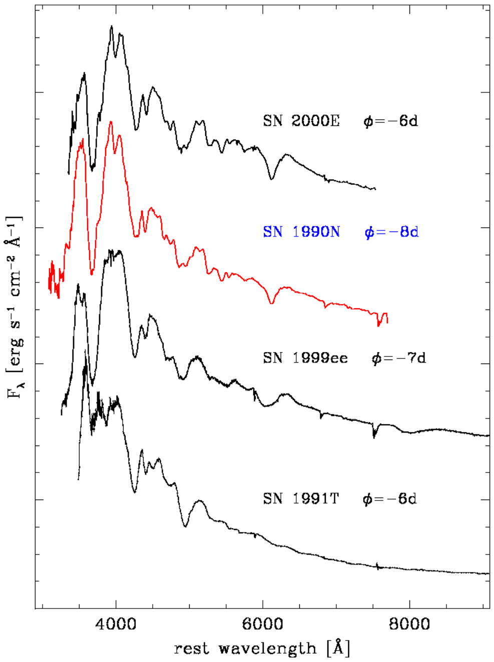

Fig. 2. Comparison of the spectra of four SNIa at about one week before B maximum light. The spectrum of SN 2000E ($\Delta m_{15} = 0.94$) is similar to the prototypical 1990N (1.07) while significant differences can be noticed with respect to other SNe having the same Δm_{15}, SN 1999ee (0.94) and 1991T (0.94).

It is evident that the detailed studies discussed above can be performed only when high signal–to–noise spectra of nearby objects are available.

4. Local Core–Collapse

With few noticeable exceptions core–collapse SNe are fainter than thermonuclear ones and show an extraordinary variance that makes them unappealing as standard candles. Since they are strongly associated to Population I, we belive that their heterogeneity is mainly due to the different configurations of the massive progenitors at the moment of the explosion.

Thanks to its vicinity, SN 1987A was the first SN for which it has been un-

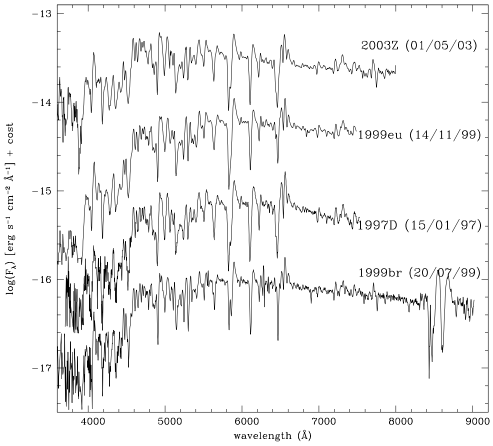

Fig. 3. TNG and ESO spectra of four low–luminosity core–collapse SNe obtained about three months after the explosion, i.e. at the end of the plateau phase. The red continua and the narrow (FWHM ~ 1000 km s^{-1}) absorption lines, the strongest of which are those of BaII, characterize these objects.

ambiguously identified the progenitor, Sk-69 202, a BSG instead of the expected RSG. The low–luminosity at early phase and the presence of a broad peak, confirmed the compact nature of the progenitor.

Although such cases are intrinsically rare and hampered by their faintness, other SNe are considered as the explosions of compact BSG. The second best example, SN 1998A, showed a photometric evolution similar to SN 1987A with slightly brighter luminosity. An individual study of this object has shown that it is the result of the explosion of a 25 M$\odot$ star which ejected 0.11 M$\odot$ of ^{56}Ni with a total energy of the explosion 4 times bigger than SN 1987A (Pastorello et al. 2003a).

Actually the faint tail of the luminosity function of core–collapse SNe is unknown. The fact that a number of faint ($M_V < -15$) SNII have been discovered only in the last few years is indicative of strong selection effects on the general sample of SNII.

A comprehensive work on the observational properties of the lowest–luminosity SNII has been recently presented by Pastorello et al. (2003b). Although the data of some objects are incomplete, taken together they suggest a fairly homogeneous set of properties and provide a complete picture of the evolution of these objects. All objects show a clear plateau lasting ~ 100 days, with a luminosity one order of magnitude fainter than normal SNII, followed by a decline powered by the decay of ^{56}Co. The spectra evolve from a fairly normal photospheric spectrum to one characterized by narrow lines, red continuum and strong BaII lines. The slow expansion velocity is characteristic of these objects at all epochs: at the earliest epochs, the photosphere is located at layers expanding at ~ 5000 km s^{-1}, but within two months it recedes to ~ 1000 km s^{-1}. Figure 3 compares the spectra of four low-luminosity SNII at the end of the plateau phase, i.e. when they have developed the red, narrow–line spectrum. The similarity among the spectra of these four objects is striking.

All objects showing spectra like these have faint late–time tails powered by very low ^{56}Ni masses (in the range $2 - 8 \times 10^{-3}$ M$\odot$), a factors 10 (or more) lower than normal core–collapse SNe.

Because of these similarities, the question arises whether they are members of a separate class with distinct progenitors and/or explosion mechanisms, or constitute simply the extreme low–luminosity tail of a continuous distribution of otherwise normal explosions. According to Hamuy (2003) the properties of all SNII with plateau show a remarkable continuity and the values of absolute magnitude and Ni mass of the faint SNII follow the general trend. It seems therefore reasonable to believe in the continuous distribution scenario.

But, how massive are their progenitors? The modelling of the light curves of two low–luminosity SNII has shown that the inferred masses of the ejecta are large (14–20 M$\odot$) hence they are likely to originate from the explosions of massive progenitors in which the rate of infall of the material on the collapsed core could have formed a black–hole (Zampieri et al. 2003a). Opposite conclusions have been reached by Chugai & Utobin (2000) who favor low mass progenitors. A more detailed study on a large samples of SNIIP including also moderately luminosity objects is in progress (Zampieri et al. 2003b).

In addition to the indications on the progenitor mass provided by models, we are now in a position to directly identify the precursor stars of SNe in galaxies within 20 Mpc. Indeed deep, pre–explosion images with HST, and other large ground–based telescopes, can in principle reveal the presence of the precursors. This has been possible so far on archival images for a dozen of objects and has provided possible progenitors or stringent limits on their masses (e.g. Smartt et al. 2002, Van Dyk et al. 2003). Projects are underway to secure deep HST imaging of all nearby galaxies in view of the identifications of the progenitors of future SNe.

5. Conclusions

Modern equipments allow the detection of remote SNe exploded when the Universe was one third of its present age. However, we will not fully exploit this precious information if we do not pursue a deeper knowledge of the SNe of our neighborhood.

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References

Altavilla,G., Fiorentino,G., Marconi,M., 2003 MNRAS submitted
Arnett,D., 1982 ApJ 253, 785
Arnett,D., 1996, Supernovae and Nucleosynthesis (Princeton: Princeton Univ.Press)
Barbon, R., Ciatti, F., Rosino, L., 1979, A & A 72, 287
Benetti,S., Meickle,P., Stehle,M., et al., 2003, MNRAS submitted
Chugai,N., Utrobin,V.P., 2000, A & A 354, 557
Gaskell, C.M., Cappellaro, E., Dinerstein, H.L., Garnett, D., Harkness, R.P., Wheeler, J.C., 1986, ApJL 306, L77
Hamuy,M., 2003, ApJ 582, 905
Harkness,R.P., et al., 1987, ApJ 317, 355
Harkness, R.P., Wheeler, J.C., 1990, in Supernovae, ed. A.G. Petshek (Berlin: Springer) 1
Höflich,P. Khokhlov,A., Nomoto,K., Thieleman,F.K., Wheeler,J.C., 1997, in Thermonuclear Supernovae, eds. P.Ruiz–Lapuente, R.Canal & J,Isern, (NATO ASI Ser. C, 486) (Dordrecht: Kluwer), 659
Li,W., Filippenko,A.V., Gates,E., et al., 2001, PASP 113, 1178
Li,W., Filippenko,A.V., Chornock,R., et al., 2003, astro-ph/0301428
Minkowski, R., 1941, PASP 53, 224
Nomoto, K., Iwamoto, K., Suzuki,T., 1995, Phys.Rep. 256, 173
Nugent, P., Phillips, M.M., Baron, E., Branch, D., Hauschildt, P., 1995, ApJL 455, L147
Pastorello,A., Baron,E., Branch,D., et al., 2003a, MNRAS submitted
Pastorello,A., Zampieri,L., Turatto,M., et al., 2003b, MNRAS submitted
Phillips, M.M., 1993. ApJL 413, L105
Phillips, M.M., Lira, P., Suntzeff, N.B., Schommer, R.A., Hamuy, M., Maza, J., 1999, AJ 118, 1766
Riess, A.G., Press, W.H., Kirshner, R.P., et al., 1996, ApJ 473, 88
Riess, A.G., Filippenko,A.V., Challis,P., et al., 1998, AJ 116, 1009
Smartt, S.J. Vreeswijk, P.M., Ramirez-Ruiz, E., et al., 2002, ApJL 572, L147
Turatto, M., 2003, in Supernovae and Gamma–Ray Bursters, Lecture Notes in Physics, ed. K.W. Weiler (Berlin: Springer), 21.
Zampieri,L., Pastorello,A., Turatto,M., et al., 2003a, MNRAS 338, 711
Zampieri,L., et al., 2003b, in preparation
Van Dyk, S., Li, W., Filippenko, A.V., 2003, PASP 115, 1