THE RATE OF SUPERNOVAE IN NORMAL GALAXIES

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1. Introduction

The rate of supernovae (SNe) is a key number linking stellar evolution with galaxy evolution models. Stellar evolution theories predict life times, fates and nucleosysntesis yields of individual stars which are used to predicted the galaxy chemical evolution once the star formation history in the galaxy is known. Constraints to the models are the present chemical content of galaxies but also the present observed SN rate (Arimoto & Yoshi, 1987; Ferrini & Poggianti, 1993; Matteucci, 1994; Renzini *et al.*, 1993; Bressan *et al.*, 1994; Elbaz *et al.*, 1995).

Over 90% of the SNe for which adequate observations are available can be assigned to one of the three basic SN types: Ia, Ib/c or II (e.g. Harkness & Wheeler, 1990). The progenitors of the different SN types belong to different stellar population: SN II and SN Ib/c result from young massive progenitors ($M_i > 8 - 10M_\odot$), hence their rate is expected to be directly related to the star formation rate (SFR). Instead SN Ia derive from low mass progenitors in close binary systems: their rate depends mainly on the parameter of the binary population, in particular the distribution of the mass ratios and of the separations of the two components. Indeed SN Ia are found also in ellipticals galaxies, where star formation ceased several billion years ago. Therefore, the rate of the different SN types can be used as a probe of the star formation history in the different type of galaxies.

2. SN rate estimates

Observational estimates of the SN rate, can be obtained through two different approaches called respectively *fiducial sample* and *control time* methods.

The fiducial sample method is based on the assumption that, during the last 30-40 years, all nearby, bright galaxies have been throughout searched

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for SNe (Tammann *et al.*, 1994). It must be stressed that using the fiducial sample method only relative SN rate can be derived because the surveillance time is unknown. Moreover, no account is made for the fact that different SN type have different brightness and therefore different discovery probability.

These problems are eliminated by using the control time method, which is based on the detailed analysis of the log of individual SN searches. Unfortunately only for a handful of the many SN searches which have been carried out in the past decades the galaxy sample and control time are known. Among these are the visual search conducted by Evans (van den Bergh & McClure, 1994), the CCD search by the Berkeley group (Muller *et al.*, 1992), and the Asiago and Crimea photographic surveys (Cappellaro & Turatto, 1988; Tsvetkov, 1987). Because the SN sample is only made by the SNe discovered in a particular survey, in general the main caveat of this method is the small SN statistics which, however, can be improved by combining the data of different searches (Cappellaro et al. 1993a, 1993b, Turatto el al. 1994).

A comparison between recently published estimates of the SN rate is reported in Table 1. The table is divided in three sections for different galaxy morphological types. In the first column is the search identification, in the second is the number of SNe on which the SN rate estimates of columns 3 to 5 are based. Since early seventies it has been demonstrated that the rate of SNe is proportional to the (blue) galaxy luminosity (Tammann, 1974). This is why SN rates are expressed per unit of $10^{10}L_{\odot}$.

For the combined data of the Asiago+Crimea surveys, a special effort was made to estimate the errors. There are three types of uncertainties which affect the estimates: the event statistics, the errors in the input parameters and the discovery biases. The latter are particularly important since they cause a systematic under-estimate of the SN rate. Two biases have been found of particular relevance for photographic searches: the loss of SNe in the central region of distant galaxies (Shaw, 1979) and in inclined spirals. Whereas for the Asiago+Crimean surveys the first one is not of great importance (only a 10% correction need to be applied, Turatto *et al.*, 1994), the rate in late spirals must be multiplied by a factor three to account for the loss of SNe in inclined spirals. The uncertainties on this factor gives a major contribution to the error-bar on the SN rate in late spirals reported in Table 1.

Considering the relatively large errors, there is a fair general agreement between the different estimates reported in Table 1, especially uncertainties, but also a few significant disagreements. In particular the rate of SN Ia in early type galaxies based on the fiducial sample is a factor 4 higher than that derived using the control time method. Possibly, this is related to a failure in the assumption that all galaxies of the fiducial sample have been

TABLE 1. Comparison between different estimates of the SN Rates.

	No. SNe	SN rate [SNu]*		
E-S0		Ia	II+Ib/c	
Asiago+Crimea[a]	8	0.13 ± 0.06	< 0.06	
Evans [b]	2	0.14 ± 0.10		
fiducial sample[c]	14	0.51		
S0a-Sb		Ia	Ib/c	II
Asiago+Crimea[a]	17	0.17 ± 0.07	0.13 ± 0.11	0.30 ± 0.19
Evans[b]	12	$0.17 - 0.32$	$0.00 - 0.22$	$0.00 - 0.81$
fiducial sample[c]	19	0.27	$0.02 - 0.16$	$0.00 - 0.77$
Sbc-Sd		Ia	Ib/c	II
Asiago+Crimea[a]	35	0.39 ± 0.19	0.27 ± 0.18	1.48 ± 0.65
Evans[b]	9	0.10	0.20	0.60
Berkeley[d]	10	0.21 ± 0.13	0.88 ± 0.28	0.64 ± 0.28
fiducial sample[c]	61	0.27	0.43	2.21

* $1\text{SNu} = 1\text{SNe} \times (10^{10} L_\odot)^{-1} \times (100yr)^{-1}$. Rates in SNu scales as $(H/75)^2$
a – Cappellaro et al. 1993a,b; *b* – van den Bergh et al. 1994; *c* – Tammann et al. 1992; *d* – Muller et al. 1992

searched for SNe at an equal intensity level (Turatto *et al.*, 1994). Instead the surprisingly high rate of SN Ic in late spirals found by Muller *et al.* (1992) may be due to an underestimate of the peculiarity of their CCD search (Cappellaro *et al.*, 1993b). Finally, the low rate of SN II in late spirals found by van den Bergh & McClure (1994) is mostly related to the claim that the visual search by Evans is unaffected by the spiral inclination bias which, due to the poor statistics, need further confirmation.

3. Conclusions

The rate of Ib/c+II SNe is strongly dependent on galaxy type, in late spirals being at least 30 times higher than in ellipticals. That is, the rate of SNe with massive progenitors is high in galaxies with high SFR.

The rate of SN Ia in late spirals is three times higher than in ellipticals. This is not a firm conclusion because only found using the Asiago+Crimea data. On the other side the Evans search has a small statistics and the fiducial sample estimates is biased by the a priori assumption that the rate of SN Ia is constant going from early to late spirals. We should note that the initial mass of the SN Ia progenitor is more likely in the range 2–6 $M_\odot$. Therefore, even if the complex evolution of binary systems may delay the explosion for time of the order of one Hubble time and account for the SN Ia in ellipticals, a high rate is expected some 10^8 years after a star formation burst which is consistent with the Asiago+Crimea observations.

An estimate of the SN rate in our Galaxy can be obtained assuming that it is similar to that in external galaxies of the same morphological type. Adopting $Sb \pm 0.5$ for the Galaxy morphological type, $L_B = 2.0 \pm 0.6 \times 10^{10} L_\odot$ for the Galaxy luminosity and including all sources of uncertainties, we expect in a millenium 3 ± 2 SN Ia, 2 ± 2 SN Ib/c and 12 ± 8 SN II. These numbers are consistent, within the large errors, with the rates derived from historical SNe, from SN remnants and from estimated pulsar birth rates.

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