Supernova Rates[1]

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Apart from stellar winds supernovae are the only mechanism which releases chemically processed material from stars into the interstellar and intergalactic gas. They are almost exclusively responsible for the chemical enrichment of galaxies and the universe as a whole. As one of the end stages of stellar evolution and one of the production channels of pulsars and black holes supernovae are also placed at a major link of stellar and non-stellar matter. They further inject kinetic energy into the interstellar gas which may be important for gas heating, cosmic rays, and possibly the kinematics of galaxies.

Knowing the frequency of supernovae means to know the rate with which these processes occur. Having further knowledge of the temporal evolution of this frequency can provide the chemical history of galaxies. Supernova statistics are thus a main ingredient in the study of formation and transformation of matter in the universe.

Recent reviews of supernova rates has been published by van den Bergh & Tammann (1991), Tammann (1994), and Strom (1994). The visual searches have been summarized by van den Bergh and McClure (1994). A series of papers by Cappellaro et al. (1993a, b, 1997) have explored the derivation of the supernova rate in detail. SN statistics staring from the available SN catalogs and exploiting various indirect routes were presented by Tammann, Löffler, & Schröder (1994).

Supernova statistics make use of minimal information about the explosions themselves. The main ingredients are the type of the explosion and a crude description of the parent population in which the explosion occurred. This is normally restricted to the morphological type of the host galaxy. The last piece of information is the time when the explosion took place. The frequency of supernovae ν_{SN} is described as the ratio of known SNe N_{SN} over the total galaxy luminosity L_{gal} per unit time t

$$\nu_{SN} = \frac{N_{SN}}{L_{gal} \cdot t}.$$

The SN rate is normally expressed in Supernova Units (SNu) which corresponds to one supernova per 10^{10} (blue) solar luminosities per 100 years.

Although in principle easy to determine the derivation of supernova rates suffers from a number of problems. Supernovae are very rare objects. The number of supernovae in galaxies with known parameters (morphological type, luminosity, color) is rather small. There are about 60 to 80 supernovae per year, but only about 10 bright supernovae in nearby galaxies (cf. Timmes & Woosley 1997). The surveyed galaxy sample has to be well described and defined. Many supernovae occur in galaxies which are not part of the current catalogs thus being lost for the derivation of the rates. Another problem is the control times, i.e. the time

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the galaxies have actually been surveyed for supernovae. Large corrections can be incurred when the galaxies are not observed frequently.

The small number statistics becomes even more apparent when we consider that the known supernovae have to be split into a number of subsamples to become meaningful. Typically there is a subdivision into three SN types and about five galaxy morphologies, which immediately creates 15 bins to group the supernovae. With typical numbers of about 200 SNe (e.g. van den Bergh & McClure 1994, Cappellaro et al. 1997) in the sample the rates are not immune against small number statistics.

Over 1200 supernovae been discovered to date. Many of these objects are not classified and can not be used for the statistics. However, about 80% of all supernovae since 1989 have a type associated. The distribution is roughly 55% SNe Ia (thermonuclear explosions of white dwarfs) and 41% SNe II and SNe Ib/c (core-collapse in massive stars). Since SNe Ia are on average about 2 magnitudes brighter than other supernovae, they can be detected over a larger volume and thus are present at a higher percentage. Excluding all the supernovae from searches specifically target at very distant supernovae (Perlmutter et al. 1997, Leibundgut & Spyromilio 1997), which mostly are Type Ia, we arrive at a near equipartition between thermonuclear and core-collapse SNe (48% SNe Ia and 49.5% SNe II and SNe Ib/c since 1989). With the same argument as above (SNe Ia more luminous) we can immediately conclude that core-collapse SNe are more frequent than thermonuclear SNe in the nearby universe. This result is further amplified by dust obscuration which affects core-collapse SNe stronger than thermonuclear SNe.

Several corrections enter the determination of supernova rates. The best known is the Shawn effect (Shawn 1979) which describes the effect of supernovae lost in the glare of centers of galaxies. Visual and CCD searches are less affected than older photographic searches which lose the contrast in bright regions. Absorption can obscure supernovae in the discs of galaxies and if, as currently believed, core-collapse supernovae stem from massive stars and are thus more affected by dust, the derived SN statistics are skewed. Several proposals how to correct for dust have been put forward (e.g. van den Bergh & Tammann 1991). The luminosity of the various subtypes of supernovae differs by factors of about 10 and the differences in light curve shapes introduces varying control times for the SN classes. These have to be factored in when the SN rate is derived.

There are two distinct approaches to derive SN statistics. The 'search technique' uses only supernovae which have been discovered in controlled searches. The most recent and complete description of this method is given by Cappellaro et al. (1997). The advantage here is that the control times and the galaxy sample are defined very well. The drawback is the small number of supernovae in the sample. Cappellaro et al. (1997) had to discard about half of the discovered supernovae, because they appeared in galaxies which are not part of the catalogs. They were left with 110 supernovae from five searches which have lasted for almost 20 years and amounted to a total of 42500 years $\times 10^{10} L_\odot$ control time (sometimes referred to as 'galaxy years').

The 'catalog technique' makes use of all supernovae discovered in a known galaxy sample (Tammann et al. 1994). This maximizes the number of supernovae as all supernova discovered in galaxies of the sample are included in the statistics, but strong assumptions on the control time have to be made. The latter quantity can be derived very badly as serendipitous SN discoveries enter the catalogs.

Despite all these problems, there is a fair agreement for the rates of thermonuclear supernovae (Type Ia) in star-forming (spiral) galaxies. The distribution is independent of the detailed morphological type of the galaxy at about 0.2 SNu. A large discrepancy exists for old stellar systems (elliptical galaxies) for which Tammann et al. find a rate increasing to a level three times higher, while Cappellaro et al. actually find indication of slightly lower SN Ia rate in ellipticals. There is only a very small number of supernovae known in elliptical galaxies, however, and the statistics are very uncertain.

Core-collapse supernovae (Types II and Ib/c) have not been observed in elliptical galaxies. Their rate increases with the fraction of young stars in galaxies, i.e. the morphological type. The most prolific supernova producers are Sc and Sd galaxies with about 1.2 SNu. There is a discrepancy of about a factor of two in the absolute rates between Tammann et al. and Cappellaro et al. for all galaxy types. The relative rates, however, agree quite well. The SN rates in irregular galaxies are largely undetermined due to the small numbers of known SNe.

The Galactic SN rate is about 20 ± 8 per millennium. This number depends on the morphological type and the total blue luminosity of the Galaxy. There are 6 historical supernovae on record (van den Bergh & Tammann 1991) which implies that roughly 2/3 of all Galactic supernovae have been hidden. Supernovae in the Local Group have been observed in M31 (S And: SN 1885A) and in the Large Magellanic Cloud (SN 1987A). The prediction for the Local Group is slightly above 2 (excluding the Galaxy), which appears consistent. The small observational baseline, however, excludes any firm conclusion from such a comparison.

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