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# A new determination of supernova rates and a comparison with indicators for galactic star formation

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**Abstract.** We have computed new estimates of the local rates of supernovae (SNe) adding the updated log of Evans' visual search to our SN search database. In this way, we have accumulated the largest SN statistics ever assembled for this purpose.

The new SN rates are corrected on an empirical basis for the bias in the inner regions of galaxies and that in inclined spirals. We also tested an alternative approach based on the simple model proposed by Hatano et al. (1998) for the SN and dust distribution in spirals. It turns out that, although the two approaches give similar average rates, the Hatano et al. model appears to overcorrect the SN rate of distant galaxies.

We used these updated statistics to probe the SN rates with different tracers of the star formation activity in galaxies, namely integrated colors, infrared luminosities and nuclear activities. We found a clear relation between the core-collapse SN rate and the integrated galaxy color, which appears consistent with the prediction of galaxy evolutionary models. We also compared SN rates in galaxies with different $L_{FIR}$ with unfavorable outcome, and we argue that $L_{FIR}$ is not a universal measurement of SFR.

Finally, we confirm that the SN rate is not enhanced in AGN host galaxies which indicates that the nuclear engine does not significantly stimulate the extranuclear SF.

**Key words:** surveys – stars: supernovae: general – galaxies: evolution – galaxies: stellar content

## 1. Introduction

One of the frontiers of current astronomical research is the observation of supernovae at high-redshift. In fact it is expected that by using SNe Ia as distance indicators it will be possible to constrain the geometry of the Universe within a few years. Equally important and difficult, is to determine the rate of the different types of SNe as a function of redshift. The rationale is that the various types of SNe have progenitors of different ages; in particular core-collapse SN II+Ib/c result from young, massive stars and SN Ia originate from intermediate to old population stars (eg. Branch et al. 1991). Therefore, the evolution of the relative SN rates with redshift can be used to probe the average SFR rate history in galaxies and, in turn, constrain scenarios for galaxy formation and evolution.

So far, there have been only exploratory attempts in this direction (Jørgensen et al. 1997; Sadat et al. 1998; Madau et al. 1998), which however have demonstrated the potential of this approach and motivated new observational efforts.

The accurate determination of the present time SN rates is the benchmark, crucial to exploiting these efforts to the full. Another important factor is to compare the rates of various SN types with different indicators of the stellar population content of galaxies in the local Universe.

One problem with these rates is that local SNe are rare and therefore it requires several years or decades to collect sufficient statistics. In addition, in order to obtain accurate estimates of the SN rate, it is necessary to know: $i)$ the sample of galaxies which have been searched for SNe, $ii)$ the frequency and limiting magnitude of observations and $iii)$ the instruments/techniques which are used for detection in order to assess search biases.

Very few groups of professional astronomers have had the perseverance and force to carry out a SN search program long enough to be really useful for this purpose (*cf* Cappellaro et al. 1997 hereafter C97). Among the amateurs in this field, an outstanding case is the visual SN search which has been conducted by Evans since 1980 (Evans 1997). Indeed, estimates of the SN rate based on the first 10 years of Evans' SN search have already been published (Evans et al. 1989; van den Bergh & Mc Clure 1994). In this paper we will analyze the updated log of this survey which doubles the statistics with respect to previously published estimates (Sect. 2).

Following the protocol described in a previous paper (C97), we pooled together Evans' log and those of photographic searches and used the improved statistical basis to test a different approach for the correction of selection effects (Sect. 3).

We used this combined database, which is the largest ever built for such a purpose, to obtain updated estimates of the SN rates (Sect. 4). Finally, we compared the SN rates with other SFR indicators such as the far infrared luminosity, the integrated color and the activity of the galaxy.

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**Table 1.** SN rates in spirals of different inclination (not corrected for the inclination bias.)

| inc | Evans search | | | photographic searches (from C97) | | |
|---|---|---|---|---|---|---|
| | N. | N. | rate | N. | N. | rate |
| [deg] | galaxies | SNe | [SNu]* | galaxies | SNe | [SNu]* |
| 0-45 | 616 | 18 | $0.88 \pm 0.21$ | 1581 | 36 | $0.94 \pm 0.16$ |
| 45-65 | 666 | 13 | $0.49 \pm 0.14$ | 1702 | 25 | $0.59 \pm 0.12$ |
| 65-90 | 592 | 11 | $0.34 \pm 0.10$ | 1818 | 15 | $0.32 \pm 0.08$ |

* $1\,\mathrm{SNu} = 1\,\mathrm{SN}\,(100\mathrm{yr})^{-1}\,(10^{10}L_\odot^{\mathrm{B}})^{-1}$.

## 2. Evans' visual SN search

Evans began his search of SNe in 1980 using a 25 cm telescope. The observations were conducted visually, which has the advantage of being very fast and inexpensive, but the limiting magnitude for SN discovery is not very deep ($m_{\rm lim} = 14.5$ mag). At the end of 1985 the telescope was replaced with a 41 cm telescope ($m_{\rm lim} = 15.0$ mag), and most recently complemented by a 100 cm telescope at Siding Spring Observatory ($m_{\rm lim} = 16.0$).

During the almost two decades of the search, Evans collected over 200,000 individual observations, surveying a sample of more than 3000 nearby galaxies. The search resulted in the discovery of 32 SNe, and another 22 SNe, which first had been discovered by others were also detected, for a total sample of 54 SNe. These numbers qualify Evans' search as the most successful amateur SN search ever and make it very competitive even to professional searches.

For the calculation of SN rates based on Evans' search log, we used the control time method and the protocol described in C97. The essential galaxy data, that is distances, morphological types, luminosities and axial ratios, have been retrieved from the updated version of the RC3 catalog (de Vaucouleurs et al. 1991) distributed by the "Centre de Données Astronomiques de Strasbourg". With the improved SN statistics, the Poissonian errors on SN events were reduced and other sources of errors became dominant, in particular in the correction of search biases.

All SN searches suffer from specific biases and therefore it is important to compare the results of different kinds of searches. Because it is unique, Evans' visual search is especially useful for comparisons with traditional photographic surveys (C97). Specific biases in SN searches occur because SNe appear embedded in their parent galaxies. Since the detection efficiency of new objects depends on the contrast against the background, obviously it is more difficult to discover a SN in the (luminous) inner regions of a galaxy than in its outskirts. This bias is at its most pronounced if one uses a wide field/small scale telescope and a detector with a small dynamic range. Also the fraction of SNe lost is greater in more distant galaxies because of the small angular size of the galaxy image. By comparing the radial distributions of SNe in galaxies at different distances, we estimated that up to 50% of the SNe exploding in the more distant galaxies are lost in photographic searches using Schmidt telescopes. The nuclear bias seems negligible only in CCD and visual searches of nearby galaxies (C97).

A precursory examination of the general list of SNe reveals another severe bias against SN detection: that in inclined spirals. In the past, it has been claimed that this bias does not affect visual and CCD searches (Evans et al. 1989; Muller et al. 1992) but so far the evidence has been inconclusive (C97). It is thus of interest to exploit the improved statistics of Evans' visual search to address this question.

We began by calculating the overall SN rate in spiral galaxies of different inclination both for Evans' visual search and for the combined photographic search sample constructed by C97, including the SN searches of Asiago (Cappellaro et al. 1993), Crimea (Tsvetkov 1983), OCA (Pollas 1994) and Calán/Tololo (Hamuy et al. 1993). For this particular calculation we turned off the correction for parent galaxy inclination which was included in the recipe of C97. The results are reported in Table 1, where the bins were chosen to give roughly the same number of galaxies in each inclination bin. It would appear that based only on Evans' log, the SN rate in edge-on spirals is 2.6 fold less than in face-on ones. This clearly demonstrates that the bias in inclined spirals also affects visual searches and is almost as severe as in photographic searches (2.9).

The natural interpretation of this bias is that SNe occurring in the disk of inclined spirals appear on the average dimmer than those in face-on spirals because of the increased optical depth through the dust layer. As a consequence, the probability of SN discovery in inclined spirals is reduced. In line with this interpretation, it is expected that the bias is more severe in searches carried out in the blue band, (e.g. photographic searches), than in visual ones (CCD searches in the red would be even less affected).

As a first order approach to correct for the inclination bias, we can assume a plane parallel geometry for the distribution of dust in the disk of spirals. In this case the average extinction of the SN population scales with $\sec i$, where $i$ is the inclination of the galaxy disk with respect to the line of sight. We showed in C97 that this assumption results in an over-correction of the SN rate in edge-on galaxies. It was argued that this is evidence that dust is not uniformly distributed in the disk of spirals but is instead in discrete clouds. Until more evidence is available we have adopted, in analogy to C97, a conservative extinction law that is intermediate between the $\sec i$ and an empirical relation, derived from the assumption that the SN rate is the same in face-on and edge-on galaxies (see Sect. 3 for an alternative model).

When such a correction is included, we can compute the SN rates for the complete Evans search and compare it with those

**Table 2.** Comparison of the SN rate [SNu] obtained from the Evans' updated statistics (1980–1998), the first 10 years of the search (1980–1989) and the combined photographic search sample

| | Evans 80–98 | Evans 80–89 | ph. search |
|---|---|---|---|
| N. galaxies | 3068 | 1377 | 7319 |
| N. SNe | 54 | 24 | 94 |
| E-S0 | $0.17 \pm 0.06$ | $0.13 \pm 0.08$ | $0.18 \pm 0.05$ |
| S0a-Sb | $0.83 \pm 0.20$ | $1.22 \pm 0.41$ | $0.66 \pm 0.13$ |
| Sbc-Sd | $0.96 \pm 0.13$ | $1.20 \pm 0.38$ | $1.34 \pm 0.20$ |
| All* | $0.66 \pm 0.09$ | $0.81 \pm 0.17$ | $0.67 \pm 0.07$ |

* Including Sm, irregulars and peculiars.

obtained from the first ten years of the search and with those derived from the combined photographic search sample. The results are reported in Table 2 where the number of galaxies and SNe for each sample is indicated in the first two rows. We must stress that, since we adopt the same galaxy catalog, input parameters, bias corrections and numerical recipe, the differences between the columns in Table 2 are only due to the different logs of observations.

The new Evans rates are consistent with the earlier results but, at least with respect to the average value, in much better agreement with the rate from photographic searches. Looking more in detail, it appears that for early type galaxies (E-S0 and S0a-Sb) the updated Evans value is in better agreement with the photographic search rate, whereas for late spirals (Sbc-Sd) the old value was closer. We attribute these fluctuations to the small statistics of individual SN searches, which become wider when the sample is divided into bins.

## 3. An alternative model for bias corrections

As mentioned before, corrections for search biases are the most controversial step in the calculation of SN rates. In our approach (cf. C97), the correction factors are tuned to cancel the sign of the biases from the calculated SN rates regardless of their physical causes. The ideal would be to build a model for the dust and SN distribution which is consistent with the present data on galaxies and SN progenitor populations and derive from it estimates of the biases.

In a recent paper, Hatano et al. (1998) described a simple model based on an assumed distribution of the dust and SN populations which predicts that, because of extinction, SNe in inclined spirals appear on average dimmer and shoe a much wider magnitude scatter than those in face-on spirals. Moreover, because the dust distribution peaks in the central regions of galaxies, this effect is more pronounced for SNe occurring in those regions.

This provides an alternative to the classical explanation of the selection effect in the central region of galaxies which would thus derive from the enhanced extinction of SNe instead of the reduced luminosity contrast. According to this scenario, the bias would be most severe in dust, inclined spirals and, because of the small scale height, for core collapse SNe. Indeed, all these features were found in the observed SN sample (Table 1 of Cappellaro & Turatto 1997).

**Table 3.** The SN rate corrected using the Hatano et al. (1998) model

| galaxy type | Ia | rate [SNu] II+Ib/c | All |
|---|---|---|---|
| S0a-Sb | $0.27 \pm 0.08$ | $0.63 \pm 0.24$ | $0.91 \pm 0.26$ |
| Sbc-Sd | $0.24 \pm 0.10$ | $0.86 \pm 0.31$ | $1.10 \pm 0.32$ |
| Spirals* | $0.25 \pm 0.09$ | $0.76 \pm 0.27$ | $1.01 \pm 0.29$ |

* Includes types from Sm, irregulars and peculiars.

A special characteristic of the Hatano et al. model is that core collapse SNe do not occur within 3 Kpc of the center of the galaxy. Therefore SN II or Ib/c do not appear in the central regions of face-on galaxies although an increasing number of core collapse SNe appears to be projected on the centers of the more inclined spirals due to projection effects. In any case, type Ia SNe are more highly concentrated than type II or Ib/c. Though Hatano et al. claim that the observations confirm their model, we should mention that van den Bergh (1997) and Wang et al. (1997) reached the opposite conclusion on the basis of similar data.

Even if the Hatano et al. model should be considered as exploratory given the above controversy, it is of interest to test how adopting it can change the SN rate estimates. We thus have replaced the empirical bias corrections mentioned in Sect. 2 with the observed SN luminosity distribution for each SN type in spirals of different inclination derived from the Hatano et al. (1998) model. Then we computed the control times for each bin of the luminosity function for each galaxy and SN type. The total control time was obtained as the weighted average according to the observed luminosity distribution.

The results of this calculation are shown in Table 3. Taken at face value and compared with the empirical bias corrections (Table 4), we found that by using the Hatano et al. model, the SN Ia rate in the entire sample of spirals results 10–20% higher and the SN II+Ib/c rate 15% smaller. These differences all fall within the errors and should not be considered significant.

We notice, however, that by adopting the Hatano et al. model the SN rate in edge-on spirals remains 1.5 times smaller than in face-on spirals, and that the rate in intermediate inclination spirals is even smaller. Slightly increasing the optical depth of the dust layer helps but does not solve the problem.

A more perplexing feature of the bias corrections based on the Hatano et al. model is that it produces SN rates which increase with galaxy distances: the rate in galaxies with $v > 3000\,\mathrm{km\,s^{-1}}$ results almost twice that in galaxies with $v < 3000\,\mathrm{km\,s^{-1}}$. This could be resolved by reducing the average reddening but which is the opposite of the previous recommendation. This apparent contradiction may simply indicate that, as already suggested, the SN progenitors and dust distributions in real galaxies are more complex than in this simple exploratory model. In conclusion, though the approach seems promising, the Hatano model needs further refinement and in the mean-

**Table 4.** SN rate(in SNu) from the combined search sample.

| galaxy type | N. SNe* Ia | Ib/c | II | rate [SNu] Ia | Ib/c | II | All |
|---|---|---|---|---|---|---|---|
| E-S0 | 22.0 | | | $0.18 \pm 0.06$ | $< 0.01$ | $< 0.02$ | $0.18 \pm 0.06$ |
| S0a-Sb | 18.5 | 5.5 | 16.0 | $0.18 \pm 0.07$ | $0.11 \pm 0.06$ | $0.42 \pm 0.19$ | $0.72 \pm 0.21$ |
| Sbc-Sd | 22.4 | 7.1 | 31.5 | $0.21 \pm 0.08$ | $0.14 \pm 0.07$ | $0.86 \pm 0.35$ | $1.21 \pm 0.37$ |
| Others# | 6.8 | 2.2 | 5.0 | $0.40 \pm 0.16$ | $0.22 \pm 0.16$ | $0.65 \pm 0.39$ | $1.26 \pm 0.45$ |
| All | 69.6 | 14.9 | 52.5 | $0.20 \pm 0.06$ | $0.08 \pm 0.04$ | $0.40 \pm 0.19$ | $0.68 \pm 0.20$ |

* Similar to C97, 10 unclassified SNe have been redistributed among the three basic SN types according to the observed distribution that is 100% Ia in E-S0, in spirals: type Ia 35%, type Ib 15%, type II 50%.
\# Others includes types Sm, Irregulars and Peculiars

while we decided to maintain the *empirical* bias corrections of C97.

## 4. SN rates and indicators of the galactic SFR

Once we had verified that the SN rates derived from Evans' visual search are similar to those obtained from photographic searches and decided the correction for search biases, we merged all search logs in a single database. In this way we obtained an improvement in the statistics compared to C97 (from 110 to 137 SNe) and equally important we balanced the weights of different types of searches (over one third of the SNe in the new sample were discovered in Evans' visual search).

The SN rates computed using these updated statistics are reported in Table 4[1] where errors include not only event statistics but also uncertainties in the input parameters and in the bias corrections. The differences with C97 are small ($< 15\%$) and well within the errors. We notice that in C97 the SN Ia rate appeared to increase when progressing from early to late type galaxies whereas this effect had now nearly vanished. The relatively low rates of SN Ib/c compared with SNII were, instead, confirmed.

The normalization of the SN rate to the galaxy blue luminosity has been introduced after the demonstration that the former scales with the latter. This is convenient because $i)$ integrated $B$ magnitudes are available for a large number of galaxies and $ii)$ the B luminosity for a given galaxy type scales with the total mass at a first approximation. Physically, the blue luminosity is a good tracer of the young stellar population in starburst galaxies, but not in normal galaxies where a considerable fraction of the continuum luminosities is produced by old stars also in the blue (Sage & Solomon 1989; Kennicutt 1998).

In principle, by using different photometric bands should be possible to sample selected stellar populations and hence to obtain useful information for progenitor scenarios. For instance, van den Bergh (1990) and Della Valle & Livio (1994) normalized the rate of SN Ia to H and K luminosity: in these bands the role of old stars in all galaxy types is dominant. If all SN Ia result from low mass stars we would expect the SN Ia rate per unit of H and K luminosities not to be correlated to galaxy type. The fact that the rate in these units increases considerably when moving from ellipticals to late spirals was taken to indicate that a significant fraction of SN Ia result from intermediate age stars. Even if their conclusion is probably correct, it must be stressed that these estimates were not direct measurements but a simple scaling of the SN rates in unit blue luminosity based on the assumption of an average B-H and B-K color per galaxy type. Because H and K photometry is available only for a small fraction of the galaxies in our sample, unfortunately, the SN rate in these units cannot be directly measured.

It would also be of interest to estimate the rates of SNe, in particular of core collapse SNe, in galaxies with different star formation rates (SFR).

The different diagnostic methods which are used to probe SFR in galaxies have been reviewed in a recent paper by Kennicutt (1998). Because we are limited by the SN statistics we need tracers that are available for large samples of galaxies. In this respect, integrated colors and far infrared (FIR) luminosities are particularly appealing.

### *4.1. SN rates and galaxy integrated colors*

Integrated broad band colors are very useful for statistical purposes, as they are reliable indicators of the galaxy stellar population with bluer galaxies expected to host stars that are younger and more massive than redder ones. Colors are most interesting because, by using evolutionary synthesis models, it is possible to estimate the SFR per unit mass or luminosity required to produce a given integrated color for a given stellar population. It is well known that along the Hubble sequence the galaxy color becomes bluer moving from early to late types and that this corresponds to a sequence in SFR which is virtually zero in ellipticals and maximum in late spirals. However, especially in spirals, there is a significant dispersion in the average color from galaxy to galaxy, indicating that SFR can vary significantly even for a given Hubble type.

Conveniently, $(B-V)^0_T$ and $(U-B)^0_T$ colors, corrected for galactic and internal extinction are listed in the RC3 catalog for a fair percentage of the galaxies of our sample (24% and 19% respectively). From these we derived also $(U-V)^0_T$ colors which, allowing for the extended wavelength baseline, are more sensitive SFR indicators. For each bin of galaxy morphologi-

[1] Through this paper we assumed $H_0$=75 km s$^{-1}$ Mpc$^{-1}$. SN rates reported in this paper can be transformed to other values of the Hubble constant multiplying by $(H_0/75)^2$

**Table 5.** SN rates in SNu for galaxies with integrated colors bluer and redder than the average.

| galaxy | blue galaxies | | | red galaxies | | |
|---|---|---|---|---|---|---|
| type | $\langle(B-V)_T^0\rangle$ | Ia | II+Ib | $\langle(B-V)_T^0\rangle$ | Ia | II+Ib |
| E-S0 | 0.86 | $0.3 \pm 0.1$ | | 0.95 | $0.2 \pm 0.1$ | |
| S0a-Sb | 0.60 | $0.2 \pm 0.1$ | $0.6 \pm 0.2$ | 0.80 | $0.2 \pm 0.1$ | $0.5 \pm 0.2$ |
| Sbc-Sd | 0.45 | $0.1 \pm 0.1$ | $1.5 \pm 0.3$ | 0.62 | $0.3 \pm 0.1$ | $0.9 \pm 0.2$ |
| All* | 0.56 | $0.2 \pm 0.1$ | $1.0 \pm 0.2$ | 0.88 | $0.2 \pm 0.1$ | $0.1 \pm 0.1$ |

| galaxy | blue galaxies | | | red galaxies | | |
|---|---|---|---|---|---|---|
| type | $\langle(U-V)_T^0\rangle$ | Ia | II+Ib | $\langle(U-V)_T^0\rangle$ | Ia | II+Ib |
| E-S0 | 1.26 | $0.3 \pm 0.1$ | | 1.48 | $0.2 \pm 0.1$ | |
| S0a-Sb | 0.67 | $0.2 \pm 0.1$ | $0.9 \pm 0.3$ | 1.12 | $0.2 \pm 0.1$ | $0.4 \pm 0.2$ |
| Sbc-Sd | 0.28 | $0.2 \pm 0.1$ | $1.7 \pm 0.5$ | 0.62 | $0.3 \pm 0.1$ | $0.8 \pm 0.3$ |
| All* | 0.54 | $0.2 \pm 0.1$ | $1.1 \pm 0.2$ | 1.32 | $0.2 \pm 0.1$ | $0.1 \pm 0.1$ |

∗ Including Sm, irregulars and peculiars.

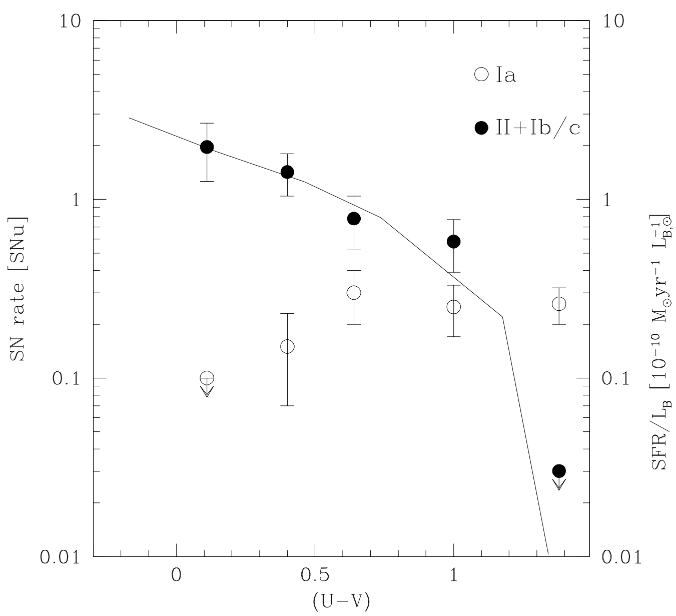


**Fig. 1.** SN rates in SNu (left-hand scale) in spirals with different U-V color (for this plot early and late spirals have been considered together). Filled symbols are core-collapse SN II+Ib/c and open circle are SN Ia. Error-bars only accounts for the SN statistics. The line gives the SFR rate per unit B luminosity (right-hand scale) for galaxies with different colors as predicted by the evolutionary synthesis models of Kennicutt (1998). The surprising coincidence of the two scales can be partially understood by simple units conversion (see text).

cal types we divided the galaxies into subsamples, containing galaxies bluer and redder than the global average. We then computed separately the SN rates for each of these subsamples. The results are reported in Table 5, where the galaxy types are in col 1, the average colors for the galaxies of the specific subset are in cols 2 and 5, the SN rates in SNu for SN Ia and for core-collapse SNII+Ib/c in cols 3–4 and 6–7.

As expected, the rate of core collapse SNe (II+Ib/c) is higher in the bluer spirals. By using B-V color this effect is seen only for late spirals (the rate is higher by a factor of 1.7 for Sbc-Sd), but becomes clear for all spirals when using U-V color (over a factor of 2). Instead the rate of SN Ia is, within the uncertainties, independent on galaxy colors.

With regards to the rows labeled “All” (which includes galaxies of all types) we should note that dividing galaxies into bluer and redder colors to a large extent corresponds to separating them into early and late type galaxies. Therefore the great difference in the core collapse SN rates in bluer and redder galaxies simply reflects the fact that core collapse SNe are not found in early type galaxies.

We can compare the observed SN rates with the predicted SFR in galaxies of different colors. This is done in Fig. 1 where the dots represent the SN rates in SNu (left-hand scale) in galaxies of different $U-V$ integrated colors and the line is the SFR per unit of blue luminosity (right-hand scale) taken from the evolutionary synthesis models of Kennicutt (1998).

In general, for a galaxy of luminosity $L_B$, because of the short life of progenitor evolution, the number of core collapse SNe per century corresponds to the number of new born stars within the appropriate mass range, namely:

$$SN\,rate[SNu] \times L_B \simeq \frac{SFR \times f_{M_L}^{M_U}}{\langle M_{SN}\rangle} \times 100$$

where $f_{M_L}^{M_U}$ is the mass fraction of stars which are born with mass in the range $M_L$ to $M_U$, the lower and upper limit for core-collapse SN progenitors, and $\langle M_{SN}\rangle$ is the average mass of SN progenitors. According to the standard scenarios, $M_L \simeq 8M_\odot$ and $M_U \simeq 40M_\odot$. Adopting a Salpeter mass function, $f_{M_L}^{M_U} \simeq 10^{-1}$ and $\langle M_{SN}\rangle \simeq 10M_\odot$ which compensate the factor 100 which accounts for the difference in the time scale.

In conclusion, even if the exact coincidence of the two scales in our figure is to some degree fortuitous, the nice agreement of the SFR measured through core collapse SN rates and that deduced by synthesis modeling for “average” spiral galaxies, lends support to the general scenario for stellar population evolution.

Conversely, the fact that the rate of SN Ia shows no dependence on the galaxy U-V color requires a significant delay between the SFR episodes and the onset of SN Ia events.

The relation between core collapse SN rates and colors provides a useful tool for the comparison of local and high-$z$ SN rates. Indeed, for galaxies at high-$z$ integrated colors can be measured relatively easily, whereas morphological types, requiring superb imaging, are not generally available. Conversely, it is clear that reporting the average SN rates for uncharacterized galaxy samples may turn out to be pointless for constraining galaxy evolution models.

**Table 6.** SN rates per unit FIR luminosity. $1\,\mathrm{SNuIR} = 1\,\mathrm{SN}(100\,yr)^{-1}(10^{10}L_{\mathrm{FIR},\odot})^{-1}$.

| galaxy type | SN rate [SNuIR] Ia | II+Ib/c | All |
|---|---|---|---|
| E-S0 | $1.8 \pm 0.8$ | | $1.8 \pm 0.8$ |
| S0a-Sb | $0.6 \pm 0.2$ | $2.0 \pm 0.5$ | $2.7 \pm 0.5$ |
| Sbc-Sd | $0.6 \pm 0.1$ | $3.5 \pm 0.6$ | $4.1 \pm 0.6$ |
| All* | $0.7 \pm 0.1$ | $2.5 \pm 0.3$ | $3.2 \pm 0.3$ |

* Includes types Sm, Irregulars and Peculiars.

### 4.2. SN rates and galaxy FIR luminosities

The interest in deriving the SN rate in units of the FIR luminosities was stressed by Jørgensen (1990) who made a first attempt based on the general SN catalog. Here we report our calculations based on the control time technique.

The near infrared emission of spiral galaxies shows at least two components: a warm component associated with dust around young stars and a cool component associated with more extended dusty heated by the general stellar radiation field, including radiation from old stars. The warm emission gives a direct measurement of the SFR, but in normal galaxies it is heavily contaminated by the cool component.

In addition to the extended star formation in the disk, many spiral galaxies show an enhanced SFR in the nuclear region. The observations show that the nuclear and extended components are mostly decoupled. In these "starburst" galaxies the nuclear SFR could reach 1–1000 $\mathrm{M}_\odot yr^{-1}$ and the integrated infrared emission is largely dominated by the nuclear component (Kennicutt 1998). At the same time we expect a very high rate of core collapse SNe, which are however difficult to detect in the optical. This is because in the nuclear starburst regions one expects several magnitudes of extinction and a severe bias for optical SN searches. These considerations must be kept in mind when interpreting the results.

FIR fluxes have been measured by the IRAS survey for over 30000 galaxies in the range $10$–$100\,\mu\mathrm{m}$ and FIR magnitudes are reported in the RC3 catalog for $\sim 30\%$ of the galaxies of our sample. They have been converted to units of solar FIR luminosites using the relation:

$$\frac{L_{\mathrm{FIR}}}{L_{\mathrm{FIR},\odot}} = 10^{-0.4m_{\mathrm{FIR}}}\,3.1 \times 10^{11}\,d^2$$

where $d$ is the galaxy distance in Mpc.

First we computed the SN rates for unit infrared luminosity $L_{\odot,\mathrm{FIR}}$.

If the FIR luminosity is a direct measure of the SFR in spirals, as is often assumed, we would expect the rate of core collapse SNe per unit FIR luminosity to be constant through all galaxy types. Instead, the results reported in Table 6 show that the rate of core collapse SNe in FIR units increases almost 2 fold moving from early to late spirals, whereas the rate of SN Ia remains constant (in Table 6 we report the SN rate in SNuIR also for E-S0 galaxies, though we do not expect there to be any relation between $\mathrm{L_{FIR}}$ and SFR). We have already stressed that there are different contributing factors to FIR luminosities, and in particular early spiral galaxies often exhibit low temperature, relatively high FIR luminosities attributable to dust heating from the general stellar radiation field, and not directly related to SFR (Kennicutt 1998).

It has been claimed that a more reliable discriminant of the SFR is the infrared excess $\mathrm{L_{FIR}/L_B}$ (eg. Tomita et al. 1996). This is because by normalizing to the blue luminosity we partially remove the effect of the general radiation field. In Table 7 we report the SN rates in SNu for galaxies with different infrared excess, along with that of galaxies not detected by IRAS. Though in general we cannot translate "not detected" into a precise upper limit, it is reasonable to assume that, for our RC3 galaxy sample, the average FIR luminosity of the undetected sample is smaller than that of the detected sample. Support for this belief comes from the fact that the distance distributions of the detected and not detected RC3 galaxy samples are similar.

The rate of core collapse SNe is higher in the IR detected galaxies compared with the not detected sample, whereas this is not the case for SN Ia (Table 7) whilst there are no significant differences between galaxies with small and large infrared excess. This again supports the idea that, whereas a fraction of the FIR luminosity originates from SF regions, the other contributing factors to the IR emission of galaxies eliminate, at least in normal galaxies, the relation between $\mathrm{L_{FIR}}$ and SFR.

### 4.3. SN rates in active galaxies

It is generally believed that nuclear activity stimulates the SF (Rodriguez-Espinoza et al. 1987) and therefore that the rate of core-collapse SNe in AGN must be higher than in normal galaxies. An open issue is whether the SF is stimulated throughout the whole AGN host galaxy or only in the circumnuclear region. From the observational point of view, in the first case we would expect an enhanced detection rate, whereas due to the high extinction in the nuclear starburst regions this may not occur in the latter case.

To address this question we crossed our RC3 galaxy list with the Catalog of Quasars and Active Galactic Nuclei of Véron-Cetty & Véron (1998) (distributed by the CDS). This catalog contains a list of almost 15000 quasars and AGN most of which are too distant for normal SN searches (only $\sim 1100$ have recession velocities smaller than $15000\,\mathrm{km\,s^{-1}}$).

**Table 7.** SN rates in SNu for galaxies with different infrared excess

| galaxy | not detected by IRAS | | $L_{FIR}/L_B \leq 0.35$ | | $L_{FIR}/L_B > 0.35$ | |
|---|---|---|---|---|---|---|
| type | Ia | II+Ib/c | Ia | II+Ib/c | Ia | II+Ib/c |
| E-S0 | $0.2 \pm 0.1$ | | $0.4 \pm 0.2$ | | $< 0.5$ | |
| S0a-Sb | $0.2 \pm 0.1$ | $0.3 \pm 0.2$ | $0.2 \pm 0.1$ | $0.5 \pm 0.2$ | $0.3 \pm 0.1$ | $1.1 \pm 0.4$ |
| Scd-Sd | $0.3 \pm 0.1$ | $0.7 \pm 0.3$ | $0.2 \pm 0.1$ | $1.0 \pm 0.2$ | $0.2 \pm 0.1$ | $1.2 \pm 0.3$ |
| All* | $0.2 \pm 0.1$ | $0.2 \pm 0.1$ | $0.2 \pm 0.1$ | $0.9 \pm 0.1$ | $0.3 \pm 0.1$ | $1.1 \pm 0.2$ |

* Including Sm, irregulars and peculiars.

We found that 283 galaxies out of our combined RC3 sample, (∼ 3%) are also listed in the Vèron-Cetty & Vèron catalog (this simply reflects the relative occurrence of AGN in the local Universe). Most of them (∼ 88%) are Seyfert and the rest HII galaxies. In these galaxies our searches have discovered 17 SNe, that is 12% of the total SN sample. This could be taken as evidence that the SN rate in AGN is enhanced compared with the general sample.

However, when the control time method is applied, the average SN rate in the AGN sample is $0.6 \pm 0.1$ SNu ($0.4 \pm 0.1$ SNu for core-collapse SNe), identical to that of the general sample ($0.7 \pm 0.1$ SNu for all SNe and $0.5 \pm 0.1$ SNu for core-collapses). We note that the AGN sample shows roughly the same distribution of morphological types as the general sample.

There are two reasons why the high detection rate in our AGN galaxy sample does not reflect in higher SN rates in SNu. First of all, the average control time for a galaxy of the AGN galaxy sample (5.08 yr) is almost twice that of the general galaxy sample (2.67 yr). Secondly, the galaxies of the AGN sample are over 2 times more luminous ($\langle L_B \rangle = 3.1^{10} L_\odot$) than the average "normal" galaxies ($\langle L_B \rangle = 1.4^{10} L_\odot$). This stresses the risks of interpreting statistics derived from general SN samples and not from actual search logs.

A similar conclusion was reached by Richmond et al. (1998) as the result of a dedicated SN search in 142 nearby starburst galaxies. They obtained 1.1 SNu (scaled to $H_0 = 75$) for the total rate and 0.7 for core-collapse only, somewhat larger than our corresponding estimates. However, their statistical error is also quite large (they had a sample of only 5 SNe) and allowing also for the different computational protocols, the difference should not be regarded as significant.

The conclusion is that the SN rate in active galaxies is the same as in normal ones (cf Petrosian & Turatto 1995). More precisely, this finding only applies to the AGN host galaxies and not to the AGNs themselves, which because of the high extinction rate cannot be probed by optical SN searches. Therefore our claim is that the nuclear engine does not significantly stimulate the SFR outside the nuclear region of the host galaxy.

## 5. Conclusions

We have presented new estimates of the SN rates in galaxies, obtained by including the updated log of the Evans' visual SN search in our database. In this way we have obtained a sample of 137 SNe in a reference sample of about $10^4$ galaxies. Based on the comparison between visual and photographic surveys we tested the effectiveness of the bias corrections and verified that they are consistent with our understanding of galaxies and SN progenitors. In particular, we show that the Hatano et al. (1998) simple model for the SN and dust distributions in galaxies explains, at least to the first order, both the bias in the nuclear region and in inclined spirals, though actually some refinement is needed before it can be used to correct SN rates.

The new rates have been compared with other tracers of the average SFR in galaxies. We found that the rates of core-collapse SNe are higher in bluer spirals, while the same is not true for SNIa. This was expected, since bluer galaxies host stars that are younger and more massive than redder ones. In particular, we find that the correlation between galaxy colors and core-collapse SN rates is similar to that predicted by the evolutionary models of Kennicutt (1998).

We have found that there is not a direct relation between core-collapse SN rates and FIR luminosities confirming that FIR luminosity is not a universal measurement of SFR. This can be explained by considering that FIR emission in galaxies at least in the normal ones, is made up of different components and not exclusively related to young stars.

Finally, our data confirms previous findings that the SN rates in AGN host galaxies are not enhanced. This conclusion does not apply to the nuclear starburst regions which cannot be probed by current SN searches.

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