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Low Luminosity Type II + Ib,c Supernovae ⋆

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Abstract. A combined sample has been constructed of supernovae of types II or Ib,c in our Galaxy and in external galaxies nearer than 4 Mpc. It is concluded that the luminosity function remains relatively flat down to $M_V = -13$ to -14. Supernova rates obtained from traditional extraglactic samples should probably be increased by a factor of 1.5 - 2. A relatively simple observational programme could yield more definite answers in five to ten years time.

Key words: supernovae:general – ISM:supernova remnants

1. Introduction

In principle the determination of luminosty functions (LF) is a straightforward matter: one counts in a distance limited sample all objects of a certain class with absolute magnitudes M_V in suitable intervals. It is not even necessary to be complete in the sense of counting all objects, as long as the selection of the counted objects is independent of M_V. In practice, of course, uncertain distances, magnitude dependent samples and interstellar absorption may create major difficulties.

In the case of supernovae the selection effects are particularly difficult to evaluate. Many supernovae have been discovered accidently, and even in the more systematic surveys discovery will depend on a complex interplay of the surface brightness distribution in the host galaxy, absorption, seeing conditions,etc. Recent partly automated surveys for distant supernovae for cosmological purposes may suffer somewhat less from such problems, but they cover only small parts of the sky and only the brighter part of the LF. Low luminosity supernovae may be found only in very nearby galaxies for which until recently the distances have been particularly uncertain.
It is therefore not surprising that widely differing LF for type II supernovae (SN II) are found in the literature. Tammann & Schrőder (1990) determined a LF of Gaussain form on the assumption that there are no major incompleteness effects out to the distance of the Virgo Cluster. Miller & Branch (1990) noted that in a magnitude limited sample the volume sampled varies as $L^{3/2}$ and that taking this into account would lead to a LF steeply rising towards the fainter luminosities. Since galaxies for SN surveys are frequently preselected on the basis of a complex set of criteria, the sample may not be truly magnitude limited, and Miller & Branch conclude that the LF should be somewhere between these two extremes. This leaves a very wide range of possibilities.
Other arguments have been used to constrain the LF of SN II. Since it should be more or less complete at the high luminosity end, one could add the requirement that the total supernova rate should not exceed the rate of formation of stars in the relevant mass range. However, neither the rate of star formation nor the mass range and other factors which determine whether a star becomes a SN II or Ib,c are known with certainty.

In the following we shall combine the SN II and SN Ib,c. Both are believed to have massive progenitors. In the case of the historical Galactic SN there is no way to distinguish the two, while also in the case of extragalactic supernovae the distinction is not always clear. It is possible that the luminosity function of the SN Ib,c is narrower than that of the SN II (e.g. Miller & Branch) but the numbers are still small and the selection effects against fainter SN Ib probably severe. The results of this paper would not be substantially changed if the known type Ib were omitted.

2. The nearby sample

Supernova searches have had very different limiting magnitudes. In the more systematic surveys of nearby (Revised Shapley Ames) galaxies by Evans limits ranged from $V = 14.^m5$ to $15.^m4$ (Evans et al. 1989). Comparing the distribution of pre-1980 SN maximum magnitudes with those of Evans we find them to be similar within the errors down to about 15^{th} magnitude. We therefore assume that supernova discoveries below about V = 14-15 have not been much affected by the actual

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Table 1. Extragalactic SN II with distances ≤ 4 Mpc

SN	Type	Galaxy	V_{max}	note	m_0-M_0	note	A_V	note	M_V
1923A	II	M83	14.0:	1	28.0	6	0.4	9	-14.4
1968L	II	M83	11.9	2	28.0	6	0.4	9	-16.5
1987A	II	LMC	2.96	3	18.5	7	0.6	10	-16.1
1993J	II	M81	10.75	4	27.8	8	0.5	11	-17.6
1983N	Ib	M83	11.24	5	28.0	6	0.5	5	-17.3

(1) Barbon et al. (1979) extrapolate the light curve of Lampland (1936) to B = 12.4:.Actually the early observations of Lampland cluster around a very flat maximum at about magnitude 14, the value listed in the current version of the Asiago catalogue
(2) Asiago catalogue for B and Patat et al. (1994) for $B-V$
(3) Suntzeff & Bouchet (1990)
(4) Barbon et al. (1995)
(5) Clocchiatti et al. (1996)
(6) M83 is considered to be a member of the Centaurus Group (see the RSA, Sandage & Tammann, 1987).This group includes NGC 5253 with a cepheid based distance corresponding to $(m-M)_0$ = 28.08 ± 0.10 (Saha et al. 1995) and NGC 5128 in which from the tip of the giant branch $(m-M)_0$ = 27.8 ± 0.2 has been derived by Soria et al. (1996). We therefore adopt $(m-M)_0$ = 28.0 for the Group, including M83 (NGC 5236). Since the Group extends over somewhat more than 10^o on the sky its extent in the radial direction could be expected to give deviations from the mean of $\pm\ 0.^m2$.
(7) The distance of 50 kpc for the LMC has generally been adopted in the recent literature and is consistent with the cepheid derived distances under (5) and (7).
(8) Cepheid based distance by Freedman et al. (1994)
(9) From the maps of Burstein & Heiles (1982) the absorption in our Galaxy is A_V = 0.19.To this we add the average internal extinction in M83 from the RSA of $A_B = 0.^m31$. For the Ib SN 1983N in the same galaxy a total $A_V = 0.^m5$ was inferred by Clocchiatti et al. (1996)
(10) West et al. (1987)
(11) Freedman et al. (1994) found for the cepheids in M81: $E_{(B-V)}$ = 0.03. However, from Na I absorption data for the SN (Benetti et al. 1994, Vladilo et al. 1994) much higher values would be inferred ($A_V \approx 1.5$) but from the 2200 Å absorption feature $A_V = 0.^m22$ (Wamsteker et al. 1993)

V values. If we wish to extend the LF to around $M_V = -13$ to -14 it follows that only supernovae out to 4 Mpc distance will have been detected with acceptable completeness. There are only four SN II and one SN Ib,c nearer than 4 Mpc (table 1) which have tolerably well determined types and magnitudes at maximum in the Asiago Supernova Catalogue (Barbon et al. 1989, and its update in electronic form of 6 June 1997).

During the last millennium six supernovae have been seen in our Galaxy. Their distances are typically 3 $\pm$1 kpc and the absorption A_V is of the order of maybe $2.^m5$, except for Cas A very close to the Galactic plane. The limiting magnitudes for the far Eastern "surveys" are believed to be somewhere in the range of V = 0-1. These supernovae, therefore, again give information on the luminosity function down to somewhere around $M_V = -14$. Four of these SN were probably SN II or SN Ib,c. They are listed in table 2. In the past SN 1604 (Kepler) was frequently taken to be a SN Ia, but Bandiera (1987) has shown rather convincingly that it had a massive progenitor which suffered substantial mass loss. The relatively high masses of SN 1054 and SN (Cas A) and the X-ray point source in 3C 58 have generally been taken as evidence of their type II or Ib,c character.

3. The LF of SN II out to the Virgo Cluster

Tammann & Schrőder (1990) constructed the SN II luminosity function on the basis of a sample (from an earlier version of the Asiago Catalogue, Barbon et al. 1989) of 22 objects nearer than the Virgo Cluster, the distances being determined from the Virgo infall model of Kraan-Korteweg (1986) with an infall velocity of 220 km s^{-1} and a Hubble constant of 50 km s^{-1} Mpc^{-1}. We have removed from the sample the three objects in table 1 with $D \leq 4$ Mpc. Further we have deleted 1982F which in the 1997 version of the Asiago Catalogue has only a minimum value for the luminosity at maximum, and we have added 1909A with $M_B = -16.1$, 1985L with $M_B = -19.3$ and 1991G with $M_B = -15.9$. Furthermore we have converted to M_V, where V magnitudes were available (Patat et al. 1994), taken $M_V = M_B$ where not, increased the pg magnitudes by $0.^m3$ to obtain B magnitudes as suggested by Patat et al. (1994) in their analysis of the light curves of SN II in the Asiago Catalogue and made some additional changes when the magnitudes in the current Asiago Catalogue wre different from those in the earlier version. We also took the Galactic absorption from the Burstein & Heiles (1982) charts rather than from the RAS. This makes no significant difference except for the SN in NGC 6946 at b = 11^o which become one magnitude brighter. The result is a sample of 22 SN II between 4 and 23.7 Mpc.

Table 2. Galactic Supernovae of Type II or Ib,c.

Year	Name	V_{max}	note	A_V	note	D(kpc)	note	M_V
1054	Crab Neb.	-4.5	1	1.4	3	2	7	-17.4
1181	3C 58	0	1	1.5	4	2.6	8	-13.6
1604	Kepler	-2.5	1	2.8	5	4	9	-18.3
1680	Cas A	>2:	2	5.0	6	3.4	10	>-15.7

(1) Clark & Stephenson (1982)
(2) According to Ashworth (1980) the star "Cas 3" at magnitude 6 seen by Flamsteed which subsequently vanished may have been the SN of Cas A. Of course, this does not give much information about V_{max}. Since in 1670 and 1673 two novae were discovered, CK Vul and Nova Pup with V_{max} = 2.6 respectively 3, we assume that a few years later a star with $V_{max} < 2$ would have been noted
(3) Véron-Cetty & Woltjer (1993)
(4) Fesen (1983) obtains $A_V = 1.^m8 \pm 1.^m0$ from H$\alpha/H\beta$. Green & Gull (1982) infer from H I absorption $A_V = 1.^m3$. From X-ray absorption Helfand et al. (1995) obtained log N_H = 21.5 which would correspond to about $A_V = 1.^m5$ which we adopt as an average
(5) Blair et al. (1991)
(6) Hurford & Fesen (1996)
(7) Trimble (1968)
(8) Green & Gull (1982) from H I absorption measurements. However, Roberts (1972) and Brandt & Blitz (1993) show that the velocity field around the longitude ($130.^o7$) of 3C 58 is rather peculiar which makes this distance uncertain. It could be even slightly below 2 kpc
(9) Dickel et al. (1988) have measured the angular expansion of Kepler's remnant to be $0.''132$/y on average with large variations. At the northern rim where the emission is strongest $0.''092$/y was found. Blair et al. (1991) obtain a shock velocity of 1550-2000 km s^{-1} from the width of Hα in Balmer line filaments, corresponding to distances of 2.5-3.2 kpc if the average angular expansion values is taken or 3.6-4.6 kpc if the northern rim is assumed to be representative. Since tha data of Blair et al. were taken also outside this region the latter values are probably too extreme. Bandiera (1987) has presented a plausible model of Kepler's remnant which explains its asymmetry: with this model a distance of 4.5 ± 1.0 kpc is found. We adopt 4 kpc
(10) Reed et al. (1995) on the assumption that Flamsteed's star was really SN(Cas A)

Further we added to the sample five Ib, namely 1954A with $M_B = -18.6$; 1964L with $M_B = -17.9$; 1983I with $M_B = -17.5$; 1985F with $M_B = -18.2$; and 1994I with $M_V = -17.5$. So far no correction has been applied for absorption in the SN host galaxy. However, since we have applied such corrections to the nearby sample this would distort the comparison between the two samples. We therefore apply to all M_V values a modest final correction of $-0.^m2$ before constructing the LF, which is the internal absorption in an average Sbc - Sd galaxy seen face on (Sandage & Tammann 1987).

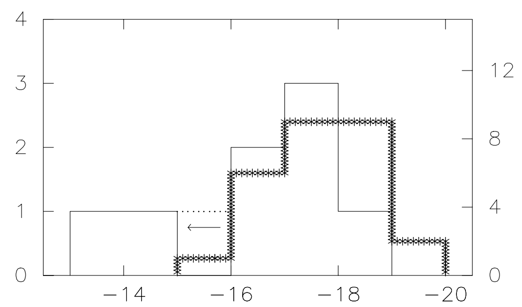

Fig. 1. The luminosity distribution in the neaby (< 4 Mpc) sample (full drawn line) and in the modified Tammann-Schrőder (beyond 4 Mpc, but nearer than the Virgo cluster) sample (crosses, right hand scale).

4. The luminosity function

In figure 1 we display the LF of the nearby sample (tables 1 and 2) and of the modified Tammann-Schrőder, up to Virgo sample. In view of the small number of objects in the nearby sample the difference between the two for $M_V < -16$ does not appear significant. What does appear to be significant is the presence of 3 SN out of 9 less luminous than $M_V = -16$, while only one such SN out 27 is found in the other sample. This is not surprising since at the median distance up to Virgo sample (18 Mpc) a SN with $M_V = -14$ would have $V = 17.1$ in the absence of absorption. It is perhaps worth noting that SN 1987A is not included among the faint supernovae; should the same exercise be done with B magnitudes this would be different.

How many such faint SN are there in an unbiased LF ? In the Galactic sample there are two for two others in the central part of the LF. In the nearby sample there is only one for four others. However, in this sample there are three SN missing because they are of unknown vintage and unknown date of maximum. They are all in M83 with photographic discovery magnitudes as follows: SN 1945B, m = 14.2, $M_B = -14.0$; SN 1950B, m = 14.5, $M_B = -13.7$; and SN 1957D, m =15.0, $M_B = -13.2$. Here the M_B values have been determined with $A_B = 0.^m5$. Of course, the magnitudes at maximum could have been much brighter. It may perhaps be significant that SN 1957D appears to have an oxygen rich remnant like Cas A (Long et al 1989). In any case these three yield an upper limit of four faint SN (including SN 1923A in table 1) for a total of four more luminous SN in the nearby extragalactic sample. We then find that the faint SN represent a fraction of between 0.5 and 1 of the SN with $M_V < -16$. If so, supernova frequencies for types II and Ib,c, obtained from relatively distant samples would have to be multiplied by a factor of 1.5 to 2. Actually the uncertainties are still greater because of the small number statistics and the possibility that the faint sample is incomplete.

Increasing the currently accepted supernova rates by a factor of 1.5-2 poses no particular problems. In fact Tammann et al. (1994) predict from standard extracgalactic SN rates that if our Galaxy is of Sbc type there should be 1.75 SN II + Ib,c per 100 years. From their model it would follow that such a rate would be just over half of the formation rate of OB stars with masses of 8 $M_\odot$ and larger. An increase in the SN rates would therefore be not unexpected. We note, however, that van den Bergh (1990) found a lower rate of star formation for such OB stars.

It has been proposed by Woltjer at al. (1997) that the remnant of SN 1181, 3C 58, is the prototype of a class of plerionic supernova remnants with very flat spectra and spectral breaks at surprisingly low frequencies. In their list of such objects is also G 291.0-0.1 (MSH 11-62) which has an extremely uncertain (X-ray absorption) distance of 2 kpc. If this distance is correct, the radius would be 1.4 pc and the SNR quite young. Because the spectra of such objects are not very different from those of H II regions a complete sample may not exist. If, in fact, there were a connection between such SNR and low luminosity supernovae, the argument by Strom (1994) about the completeness of the samples of nearby SN and SNR would not be applicable.

5. Conclusions

In the Gaussian LF determined by Tammann & Schrőder (1990) there would be five times as many SN II brighter than $M_B = -16$ as fainter. In the opposite case of a strictly magnitude limited sample Miller & Branch (1990) show that there should be more SN II with $M_B = -14.5$ to -15.5 than at higher luminosities. Here we have found that there is a faint extension to the luminosity function of SN II + Ib,c but that it will make a relatively modest increase in the number of SN brighter than $M_V = -16$ by a factor of the order of 2 or less.

Observations twice a month with CCD arrays with a limiting magnitude of $V = 20$ of the 30 most luminous face on Sc galaxies in the RAS could be sufficient to give much more definite information. Such galaxies have $L \approx 10^{11}\, L_\odot$ in B and according to Tammann et al. (1994) each should produce 13 standard supernovae per century. Taking into account the fact that not all galaxies will be visible the whole year, this would correspond to about 30 supernovae in a decade. If the number of low luminosity supernovae is half of this, some 15 should be found in that period and the luminosity function established with confidence.

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