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On the relative frequencies of core-collapse supernovae sub-types: The role of progenitor metallicity

N. Prantzos[1] and S. Boissier[2]

[1] Institut d'Astrophysique de Paris, 98bis Bd. Arago, 75104 Paris, France
[2] Carnegie Observatories, 813 Santa Barbara Str., Pasadena, Ca 91101, USA
e-mail: `boissier@ociw.edu`

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Abstract. We show that the observed ratio $N_{\rm Ib,c}/N_{\rm II}$ of the subtypes Ib,c and II core-collapse supernovae depends on the metallicity of the host galaxy, as expected on theoretical grounds. However, the observed relation differs considerably from expectations based on non-rotating models of single stars with mass loss. We argue that the predictions of recent models with rotation offer a much better agreement with observations, at least for progenitor stars with solar metallicity; calculations of models with higher and lower metallicities are required in order to substantiate these conclusions. We also suggest that systematic surveys of core collapse supernovae up to redshift z ~1 with the SNAP satellite would allow to probe the effect of metallicity on supernovae properties during the past history of the Universe.

Key words. stars: general – stars: evolution – stars: supernovae: general

1. Introduction

It has been known for sometime now that supernovae with different spectral signatures and lightcurves, such as IIP, IIL, IIdw, Ib, Ic etc., all explode by the same mechanism: the gravitational energy released by the collapse of the Fe core of a massive star is partially transferred to the stellar envelope and, under certain conditions, manages to expell it to space. Despite more than fourty years of intense theoretical investigations, the conditions for a succesfull explosion remain unclear yet (e.g. Janka et al. 2002, for a recent overview).

However, the appearance of the supernova to an external observer, i.e. its optical spectra and lightcurve, depend only little on the mechanism of the explosion. The main factor affecting the observed features of core collapse supernovae is the mass (and the size) of the H-rich envelope of the progenitor star (see e.g. Hamuy 2003, for a recent overview). This depends on the amount of mass loss suffered during the star's life. This is, in its turn, mainly a function of the stellar mass and metallicity. (Note: in the case of binary stars, the interaction of the progenitor with its companion may play an even more important role in determining the mass loss.) It is expected then that the relative numbers of the various core collapse supernovae subtypes should depend on the metallicity of the host galaxy (e.g. Maeder 1992; Mowlavi et al. 1998).

In this work we use the well-known metallicity-luminosity relationship for late type galaxies (e.g. Garnett 2002, and references therein) to show that the observed ratio $N_{\rm Ib,c}/N_{\rm II}$ between supernova of type Ib,c and II does indeed depend strongly on metallicity (Sect. 3). To our knoweledge, it is the first time that such a relation is shown to hold observationally. However, we find that the slope of that relation, as well as the value of the ratio at solar metallicity, are higher than those expected from non-rotating models of single stars with mass loss. We show that predictions of recently calculated stellar models with rotation and mass loss (Meynet & Maeder 2003) offer a quantitative agreement with observations, at least for progenitor stars with solar initial metallicity. Finally, in Sect. 4 we argue that systematic surveys of supernovae at redshifts up to z ~1, feasible with the SNAP satellite, would allow to probe the role of metallicity on supernova properties during earlier epochs in the history of the Universe.

2. Types of core collapse supernovae

In a recent comprehensive study, Heger et al. (2003a) suggested the following scheme for the progenitors of core collapse supernova types, on the basis of models of single non-rotating stars with mass loss (Fig. 1a):

1) For progenitor metallicities $Z \sim Z_\odot$, stars with initial mass $M_{\rm IN} < M_{\rm Ib,c} \sim 34\ M_\odot$ keep enough of their envelope at the end of their lives to explode as SNII (either IIP or IIL). More massive stars lose completely their H-rich envelope, become WR stars and explode as SNIb,c.

2) For $Z > Z_\odot$ $M_{\rm Ib,c}$ decreases, down to ~30 $M_\odot$ at $Z \sim 3\ Z_\odot$ (since higher metallicities favour higher mass loss rates through radiation pressure on the envelope).

Send offprint requests to: N. Prantzos, e-mail: `prantzos@iap.fr`

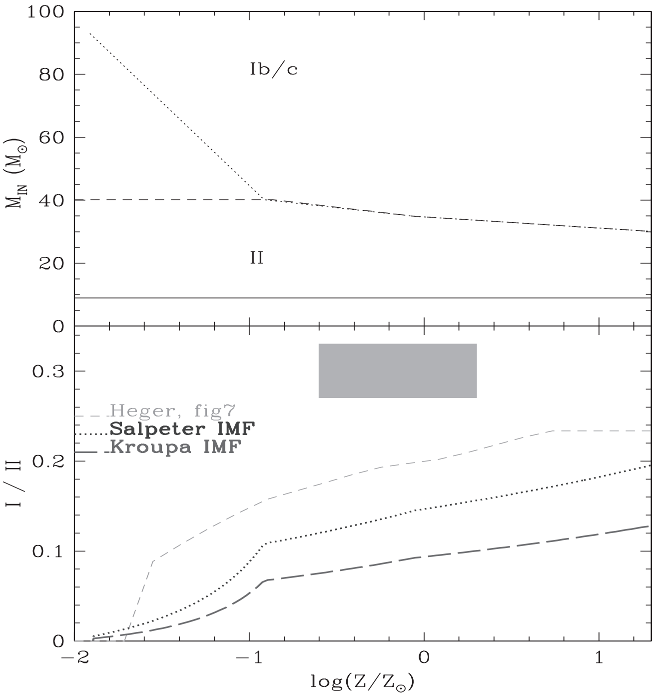

Fig. 1. *Top:* lower mass limit for core collapse supernova (*solid curve*), upper mass limit for SNII (*dashed*) and lower mass limit for SNIb,c (*dotted*) as a function of metallicity, according to the estimates of Heger et al. (2003a); for metallicities higher than 0.1 $Z_\odot$ the dotted and dashed curves coincide, but for lower metallicities stars with mass $40 < M_{\rm IN} < M_{\rm Ib,c}$ collapse to black holes. *Bottom:* ratio of $N_{\rm Ib,c}/N_{\rm II}$ as a function of metallicity, taking into account the mass limits of Fig. 1a; the *thick* curves are obtained with the IMFs of Salpeter (*dotted*) and Kroupa et al. (1993, *long dashed*), respectively, both extended up to 100 $M_\odot$. The *thin, short-dashed curve* is obtained by Heger et al. (2003a) with the Salpeter IMF extended to 400 $M_\odot$ (possibly appropriate for ~zero metallicity environments). The *shaded aerea* corresponds to the observed average ratio of $N_{\rm Ib,c}/N_{\rm II}$, according to Bressan et al. (2002, lower value) and Hamuy (2003, upper value), within the metallicity limits of the host galaxies (see Sect. 3).

3) For $Z_\odot > Z > 0.1\ Z_\odot$, weaker mass loss rates increase $M_{\rm Ib,c}$, which reaches ~40 $M_\odot$ at $Z \sim 0.1\ Z_\odot$.

4) For $Z < 0.1\ Z_\odot$, mass losses are negligible and the upper mass limit for SNII is kept at 40 $M_\odot$ (Fig. 1). That upper limit no more coincides with $M_{\rm Ib,c}$, since stars in the mass range $M_{\rm Ib,c} > M_{\rm IN} > 40\ M_\odot$ and in that metallicity range fail to explode (at least under "standard" assumptions of current models, i.e. spherical symmetry) and collapse directly to form black holes[1]. Only the most massive stars (see *dotted curve* in upper panel of Fig. 1) produce a weak SNIb,c explosion in that metallicity range.

A direct test of that scheme was recently undertaken by Smartt et al. (2003). By using high quality images of nearby host galaxies of SN prior to the explosion, and by comparing to stellar evolution tracks with mass loss but no rotation, they were able to evaluate (or put upper limits on) the mass of the progenitor stars of eight core collapse supernovae. Seven of them were SNII (either P or L) and were found to have $M_{\rm IN} < 25\ M_\odot$, in agreement with theoretical expectations. The last one (SN2002ap), classified as Ic, was found to have $M_{\rm IN} < 40\ M_\odot$ and $Z \sim 0.5\ Z_\odot$, in (marginal) agreement with the scheme proposed by Heger et al. (2003a).

In this work we propose an indirect test of the ideas of Heger et al. (2003a), concerning the *number ratio of SNIb,c to SNII core collapse supernovae as a function of metallicity*. For metallicities $Z > 0.1\ Z_\odot$, where the upper mass limit for SNII coincides with $M_{\rm Ib,c}$ this ratio is given by

$$\frac{N_{\rm Ib,c}}{N_{\rm II}} = \frac{\int_{M_{\rm Ib,c}}^{M_{\rm SUP}} \Phi(M)\,{\rm d}M}{\int_{M_{\rm INF}}^{M_{\rm Ib,c}} \Phi(M)\,{\rm d}M} \qquad (1)$$

where $M_{\rm INF} \sim 9\ M_\odot$ is the lower mass limit for core collapse supernova (Heger et al. 2003a), $M_{\rm SUP} \sim 100\ M_\odot$ is the corresponding upper mass limit (on which the value of $N_{\rm Ib,c}/N_{\rm II}$ depends very little) and $\Phi(M)$ is the stellar initial mass function. Equation (1) is obviously correct for a "steady state" situation, i.e. for a star formation rate ~constant during at least the last ~40 Myr (the lifetime of a star with mass $M_{\rm INF}$); it does not apply e.g. in the case of a starburst more recent than 10 or 20 Myr.

For metallicities $Z > 0.1\ Z_\odot$, one sees that the ratio $N_{\rm Ib,c}/N_{\rm II}$ increases monotonically with Z, since the dividing mass $M_{\rm Ib,c}$ decreases with increasing Z. This is true as far as the stellar initial mass function (IMF) remains constant with metallicity, which appears to be the case according to most current studies (e.g. Kroupa 2002). Of course, the value of $N_{\rm Ib,c}/N_{\rm II}$ depends on the form of the adopted IMF in the massive star range, as can be seen in Fig. 1b. The two thick curves are constructed, respectively, with the Salpeter IMF (a single power law with slope $X = 1.35$) and the Kroupa et al. (1993) IMF (a multi-slope power law with $X = 1.7$ in the massive star range)[2]. In both cases we assume that the IMF extends to $M_{\rm SUP} = 100\ M_\odot$. Indeed, although stars with $M_{\rm IN} > 100\ M_\odot$ might have existed in ~zero metallicity environments (Nakamura & Umemura 2001), their existence at non-zero metallicities is implausible, both on theoretical (e.g. Baraffe et al. 2002) and observational grounds (e.g. Heydari-Malayeri 2003). We assume then in the following that for $Z > 0.1\ Z_\odot$ the IMF extends only up to ~100 $M_\odot$.

An inspection of Fig. 1b shows that $N_{\rm Ib,c}/N_{\rm II}$ never exceeds ~0.2, even at the highest metallicities calculated by Heger et al. (2003a) with their non-rotating models. This is in disagreement with observations. Indeed, Bressan et al. (2002) find that in normal galaxies $N_{\rm Ib,c}/N_{\rm II} \sim 0.27$, while Hamuy (2003) argues that one out of four core collapse supernovae belongs to type Ib,c, i.e. that the ratio $N_{\rm Ib,c}/N_{\rm II}$ should be ~0.33.

In the next section we show that, by counting supernova types (and corresponding ratios) in galaxies of different metallicities, the prediction of Fig. 1b can be tested statistically. We find that the predictions of non-rotating models disagree not only with observed values at high metallicities, but also with the observed slope of the $N_{\rm Ib,c}/N_{\rm II}$ vs. metallicity relation. We

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[1] According to Heger et al. (2003a) non-"normal" supernovae, powered by jets, may occur in that mass-metallicity region; but their optical signature differs from both SNII or SNIb,c.

[2] The power-law stellar IMF of slope X is defined as ${\rm d}N/{\rm d}M \propto M^{-(1+X)}$.

suggest that models including rotation offer a physically plausible quantitative solution.

3. The $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ ratio in galaxies

The existence of a metallicity-luminosity relation is a well established fact about spiral galaxies (see Garnett 2002 and references therein). Oxygen abundances measured in the gaseous phase and at fixed fractional galactocentric radius (at the center, at one disk scalelength or at the disk half-radius) always increase with the blue luminosity of the galaxy. According to Garnett (2002) this relation can be expressed as

$$\log\left(\frac{\mathrm{O}}{\mathrm{H}}\right) = -0.16 M_B - 6.4 \qquad (2)$$

where M_B is the galaxy's blue magnitude and the metallicity is taken at the galaxy's effective radius R_{eff}. The relation is valid over ~2 orders of magnitude for O/H and over a range of ~10 mag, for spirals, irregulars and low surface brightness galaxies alike (see Fig. 2, top).

This important feature has not found a satisfactory explanation up to now. It could be due either to a greater efficiency of star formation in more massive galaxies (e.g. Ferreras & Silk 2001), to a younger age for less massive galaxies (e.g. Boissier et al. 2001), to a more important mass loss reducing the effective yield in less massive galaxies (e.g. Dekel & Silk 1986) or to some combination of these factors. Independently of its origin, this relation allows us to test statistically the theoretically predicted trend of $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ with metallicity.

We use a recent version (January 2003) of the Asiago Supernova Catalogue, presented in Barbon et al. (1999)[3]. This catalogue provides the morphological type of the galaxy, the supernovae type and the blue magnitude of the parent galaxy when possible (usually from the RC3 or the LEDA database). From the entries of the catalogue, we keep only the galaxies of spiral or irregular morphologies, (for which the metallicity-luminosity relationship applies) and which show no signs of recent starbursts (so that Eq. (1) applies); we also take into account only the core collapse supernovae, i.e. those with a clear identification as one of the types Ib, Ib/c, Ic, or II. The parent galaxy's magnitude is available for 280 of the core-collapse events. For that restricted sample, we find a value of $N_{\mathrm{Ib,c}}/N_{\mathrm{II}} = 0.27$, i.e. similar to the value given by Bressan et al. (2002). To study the effect of metallicity on the number of SN of each sub-type, we adopt magnitude bins containing each the same number of core collapse events (70). In the following we adopt errorbars $\delta N = \sqrt{N}$ for any number N, and the relative uncertainty of a ratio N/M is $\delta N/N + \delta M/M$.

In Fig. 2 (middle) we plot the number of the core collapse SN sub-types in each bin. Despite the poor statistics, it can be seen that the total number of SNII increases in the low luminosity bins, while the one of SNIb,c decreases. This is translated into a clear increase of the $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ ratio with galactic luminosity, presented in Fig. 2 (bottom).

The obvious physical explanation for the observed corelation between $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ and M_B involves the effect of metallicity, as explained in Sect. 2: more luminous and metal-rich galaxies are expected to have higher ratio of $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$. Note that the data span the metallicity range 1/3 $Z_\odot$ to 2 $Z_\odot$, i.e. the range where theoretical models predict indeed a variation of $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ with metallicity.

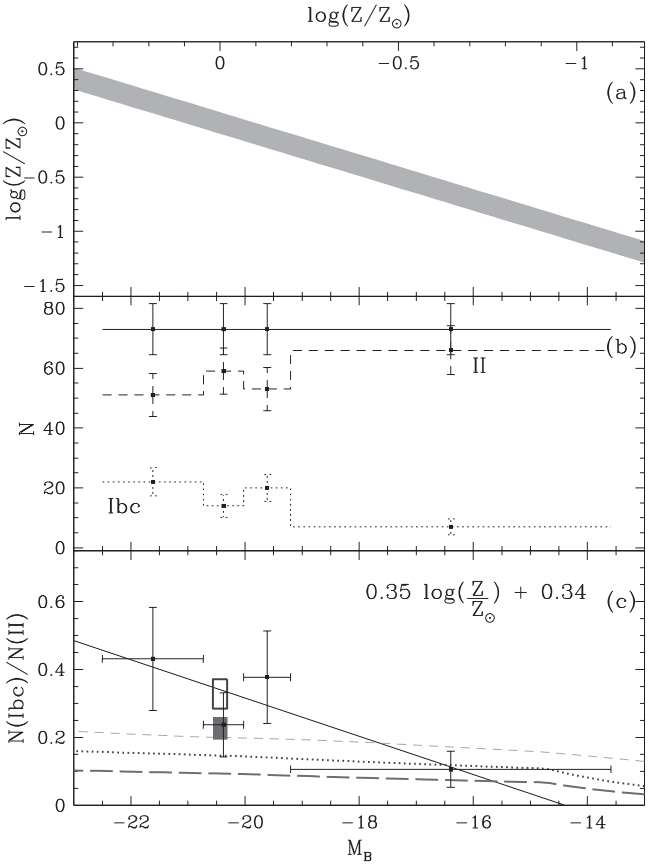

Fig. 2. **Top:** observed metallicity-luminosity relation for late type galaxies according to Garnett (2002) and Eq. (2). **Middle:** observed number of core collapse SN sub-types as a function of the host galaxy's blue magnitude M_B; bins of M_B are such that the same total number of events (70) are found in each bin; it is found that the number of SNII (*dashed*) decreases, while the number of SNIb,c (*dotted*) increases with increasing luminosity. **Bottom:** ratio $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ as a function of blue luminosity of host galaxies; the observed ratio (the *solid* line is a best fit to the data) increases with luminosity, i.e. with metallicity, more rapidly than theoretical expectations (*dotted, long dashed, short dashed* curves, with same meaning as in Fig. 1b). The *filled* and *open* rectangles at solar metallicity are obtained with the Kroupa et al. (1993) and the Salpeter IMF, respectively, when $M_{\mathrm{Ib,c}}$ is decreased to 22–25 $M_\odot$, as appropriate for rotating star models (see text).

However, before discussing further the metallicity dependence of $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$, one should account for the fact that Eq. (2) is valid at a fixed radius R_{eff}, while galaxies display important metallicity gradients and, in consequence, supernova inside a galaxy of a given magnitude are expected to occur in regions of different metallicities; this introduces, in principle, a dispersion of the $N_{\mathrm{Ib,c}}/N_{\mathrm{II}}$ ratio around some average value corresponding to the mean galaxian metallicity. The question is then whether the observed supernovae exploded in regions with metallicity close to the one given by Eq. (2), i.e. close

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[3] Available at `http://merlino.pd.astro.it/~supern/`

to $R_{\rm eff}$. An inspection of Fig. 1 in Bressan et al. (2002) shows that this is indeed the case: the distribution of observed core collapse supernovae as a function of their galactocentric distance peaks at 0.6 R_{25} (R_{25} is the radius where the B band surface brightness is 25 mag arcsec^{-2}); on the other hand, for exponential disks with "canonical" central surface brightness (μ_0 = 21.65 mag/arcsec, the Freeman value), $R_{\rm eff}$ corresponds to ~0.56 R_{25}[4]. Thus, for most of the observed core collapse supernovae, the magnitude of the host galaxies can indeed be associated to the metallicities implied by Eq. (2).

A best fit to the observed $N_{\rm Ib,c}/N_{\rm II}$ vs. metallicity relation is given by

$$\frac{N_{\rm Ib,c}}{N_{\rm II}} = 0.35 \ \log(Z/Z_\odot) + 0.34. \tag{3}$$

The theoretical $N_{\rm Ib,c}/N_{\rm II}$ ratio (i.e the curves of Fig. 1b) are also plotted in Fig. 2 (bottom), by assuming the luminosity-metallicity relation of Eq. (2). It can be seen that theory matches observations only at the bin of lowest luminosity, corresponding to a metallicity of ~0.3 $Z_\odot$. At higher metallicities/luminosities there is an increasing difference between theory and data, by a factor of 2–3 at $Z_\odot$ and up to 3.5 at ~2 $Z_\odot$. The disagreement never exceeds 2 σ but it is worrying that the observed slope is considerably more steep than the theoretical one.

Several effects might be at the origin of that discrepancy. A shallower stellar IMF than the one of Salpeter could certainly produce a larger $N_{\rm Ib,c}/N_{\rm II}$ ratio; but to match the $N_{\rm Ib,c}/N_{\rm II}$ ratio at $Z_\odot$, it would take a slope $X < 1$ for the stellar IMF (see Fig. 3), i.e. much smaller than all current empirical evidence. On the other hand, an IMF with a *metallicity dependent slope* could obviously fit to the data. However, such a variability of the IMF is not supported by observations (see e.g. Kroupa 2002 and references therein).

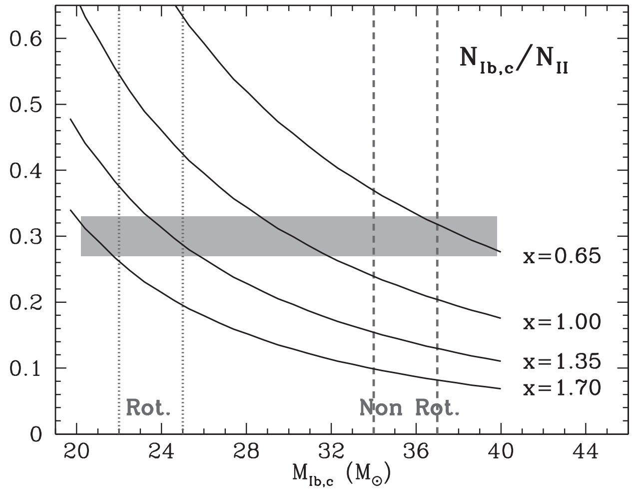

Fig. 3. The $N_{\rm Ib,c}/N_{\rm II}$ ratio as a function of $M_{\rm Ib,c}$ (the lower mass for a massive star to explode as Ib,c), for several values of the slope X of the stellar IMF ($dN/dM \propto M^{-(1+X)}$, so that 1.7 corresponds to the Scalo IMF and 1.35 to the Salpeter IMF). The two sets of vertical lines indicate the values of $M_{\rm Ib,c}$ obtained with: i) non-rotating models (*dashed*), respectively at 34 $M_\odot$ from Heger et al. (2003a) and at 37 $M_\odot$ from Meynet & Maeder (2003); ii) rotating models (*dotted*) from Meynet & Maeder (2003), respectively at 22 $M_\odot$ (stars become WNE but retain part of their H-envelope at their death) and at 25 $M_\odot$ (stars lose their entire H-envelope). Both cases concern stellar models of solar initial metallicity. The *shaded area* indicates the observed range of values of $N_{\rm Ib,c}/N_{\rm II}$ according to Hamuy (2003) and Bressan et al. (2002).

As pointed out in Sect. 2, the theoretical predictions are based on the single star models of Heger et al. (2003a), calculated with mass loss. Other ingredients, not taken into account in those models, may affect the $N_{\rm Ib,c}/N_{\rm II}$ ratio. For instance, mass loss through Roche lobe overflow in a binary system is a well known channel to form WR stars (e.g. Chiosi & Maeder 1986), which are progenitors of SNIb,c. This channel was thought to be predominant at low metallicities: Maeder & Meynet (1994) found that all WR stars in the Small Magellanic Cloud are in binaries, but argued that the WR/O ratio in different metallicity environments suggests that the fraction of the WR stars due to that channel is small at high metallicities. Recently, Foellmi et al. (2003a) performed a thorough study of the WR population of the SMC, and found that, contrary to theoretical expectations, the binary fraction of WR in that galaxy is ~40% rather than ~100% theoretically expected. Foellmi et al. (2003b) also found that the corresponding value for the LMC (which is ~3 times more metal-rich than the SMC) is ~30%. These findings weaken even more the role of binarity in WR formation at high metallicities. In fact, assuming that the binary channel contributes 20% to the Milky Way population of WR (Foellmi et al. 2003a,b), that binarity reduces the average WR mass to 19 $M_\odot$ (for solar metallicity stars), and taking into account the results displayed in Fig. 3, one sees that the expected $N_{\rm Ib,c}/N_{\rm II}$ value at solar metallicity is 0.23, i.e. still lower than observed in solar metallicity environments. Moreover, the contribution of binaries to the WR fraction and to the $N_{\rm Ib,c}/N_{\rm II}$ ratio should be independent of metallicity and cannot therefore account for the mismatch obtained in Fig. 2 (bottom) between observed and theoretical slopes.

Models of *rotating massive stars* (combined with mass loss) have been recently developed by a few groups (Maeder & Meynet 2002; Heger et al. 2003b). Meynet & Maeder (2003) find that rotation produces stars with more massive convective cores, higher effective temperatures and smaller mass left at the end of the evolution, compared to non-rotating ones. In particular, they find that the minimal mass for a star to become WR is 37 $M_\odot$ for non-rotating stars (i.e. close to the 34 $M_\odot$ suggested by Heger et al. 2003a), but only 22 $M_\odot$ for stars rotating initially at 300 km s^{-1}. In fact, such stars become only WNL stars, i.e. they keep a trace amount of their original hydrogen envelope. An inspection of Figs. 9 and 10 of Meynet & Maeder (2003) shows that stars rotating at 300 km s^{-1} with slightly higher mass, around 25 $M_\odot$, become WNE stars losing their entire H-envelope.

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[4] For an exponential disk with a scalelength $R_{\rm D}$, the surface brightness profiles has the form: $\mu(R) = \mu_0 + 1.085 \ R/R_{\rm D}$. For $\mu_0 = 21.65$, $\mu = 25$ occurs at $R = R_{25} \sim 3R_{\rm D}$. The radius within which the integral of this profile is equal to half the integral up to an infinite radius is the half-light radius $R_{\rm eff}$, and is equal to 1.865 $R_{\rm D}$. Then, $R_{\rm eff}/R_{25} \sim 0.6$.

This reduction in $M_{\rm Ib,c}$ obviously affects the $N_{\rm Ib,c}/N_{\rm II}$ ratio. In Fig. 2 (bottom) we also plot the $N_{\rm Ib,c}/N_{\rm II}$ ratio assuming $M_{\rm Ib,c} = 22$ and 25 $M_\odot$, respectively, for the Salpeter and for the Kroupa et al. (1993) IMFs and for solar metallicity only (*open* and *filled* squares, respectively). It can be seen that there is a much better agreement with the observations. As argued by Meynet & Maeder (2003), rotation provides a better fit to various observations concerning WR stars, like statistics of WR subtypes and surface abundances. According to the results displayed in Fig. 2, it also provides a nice explanation to the observed $N_{\rm Ib,c}/N_{\rm II}$ ratio, at least for solar metallicity stars. Indeed, if it is assumed that $M_{\rm Ib,c}$ is as high as 34 $M_\odot$, it requires unnaturaly low values of the slope X of a power-law IMF in order to obtain the observed $N_{\rm Ib,c}/N_{\rm II}$ ratio, as shown in Fig. 3. Only for values of $M_{\rm Ib,c}$ at least as low as 22–25 $M_\odot$, the observed $N_{\rm Ib,c}/N_{\rm II}$ ratio can be reproduced with "reasonable" values of X. We suggest that this is a further argument in favour of the rotating star models of Meynet & Maeder (2003).

Assuming that the fit of Eq. (3) represents well the metallicity dependence of the $N_{\rm Ib,c}/N_{\rm II}$ ratio, and that the only factor affecting that dependence is the variation of $M_{\rm Ib,c}$ with metallicity, one may use Eq. (1) to determine that variation. This is done in Fig. 4, for two IMFs. The thick portions of the curves indicate the region of galaxian metallicity (or blue magnitude) where $N_{\rm Ib,c}/N_{\rm II}$ has been observationally determined (i.e. between M_B values of -23 and -14 in Fig. 2c). It can be seen that $M_{\rm Ib,c}$ varies from 40–50 $M_\odot$ at $Z \sim 0.3\ Z_\odot$ to slightly below 20 $M_\odot$ at $Z \sim 2\ Z_\odot$. This observationally determined variation of $M_{\rm Ib,c}$ may offer potentially important constraints to models of massive star evolution.

We note that Bressan et al. (2002) find that the ratio $N_{\rm Ib,c}/N_{\rm II}$ in Seyfert galaxies is ~1, i.e. about three to four times larger than in normal galaxies. They explore several possible reasons for such a high ratio, including metallicity effects on $M_{\rm Ib,c}$, and they conclude that the most probable one is a recent starburst, of age smaller than the lifetime of the smallest core collapse supernova (in which case Eq. (1) is invalid). They base their quantitative estimates on non-rotating models with mass loss. We think their explanation certainly holds, but rotating models may alleviate the constraints on the age of the starburst they obtain in their Fig. 3.

4. Relative supernova frequencies in galaxies

Supernova frequencies are usually given for galaxies of different morphological types, in units of SNu (i.e. in number of SN per 100 yr and per 10^{10} $L_{B,\odot}$). The rational behind this definition of frequency units is that the galaxy's blue luminosity measures its total mass, as also suggested by the Tully-Fisher relation in the blue. Note that in starburst galaxies the blue luminosity traces rather the young stellar population, while in normal galaxies there is a significant contribution from the old, metal poor, population.

As expected then, the SN frequencies expressed in SNu depend little (if at all) on the galaxy's morphological type (e.g. Cappellaro et al. 1999; Turatto 2000), as shown in Fig. 4a. For the same reason, the ratio $N_{\rm Ib,c}/N_{\rm II}$ is also insensitive to the galaxy's morphological type (Fig. 4b) and it is of little utility

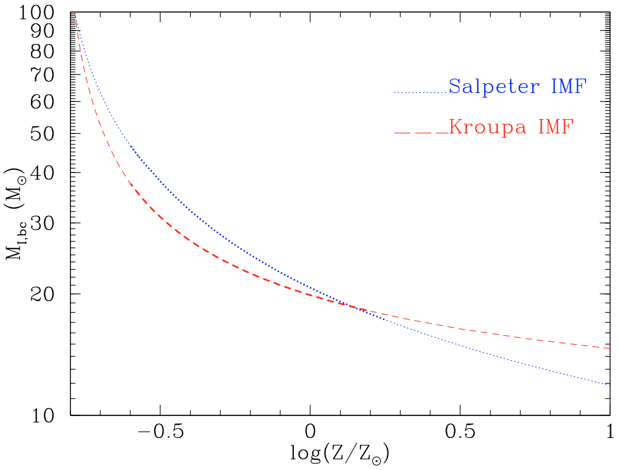

Fig. 4. Mass $M_{\rm Ib,c}$ (the lower mass for a massive star to explode as Ib,c) as a function of the initial stellar metallicity Z, estimated from Eq. (1) as to reproduce the values of $N_{\rm Ib,c}/N_{\rm II} = f(Z)$ corresponding to the fit to the observational data displayed in Fig. 2c.

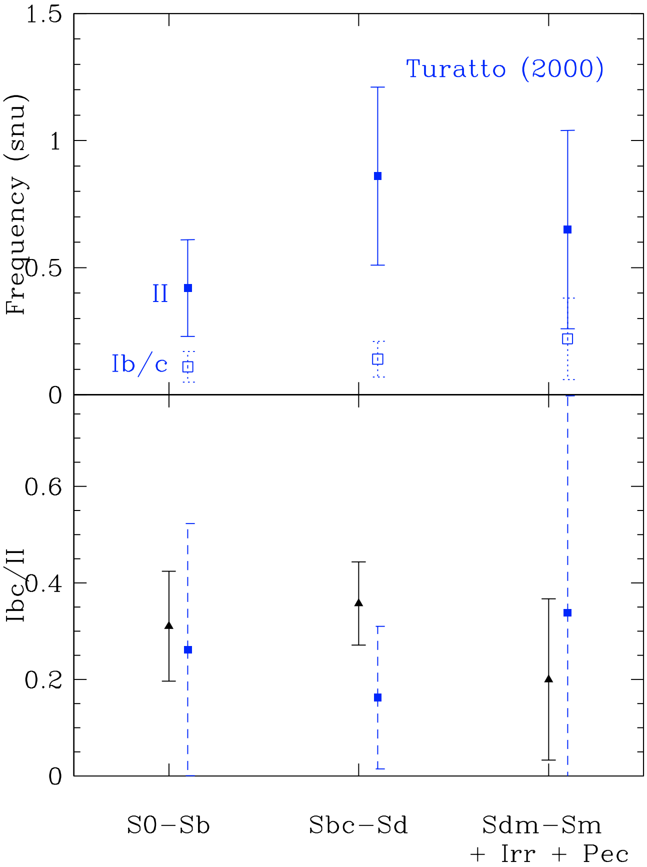

Fig. 5. *Top:* frequency of SNII and SNIb,c (expressed in SNu, i.e. number of SN per 100 yr and per 10^{10} $L_{B,\odot}$) for various galaxy morphological types (from Turatto 2000). *Bottom:* ratio $N_{\rm Ib,c}/N_{\rm II}$ in galaxies of different morphological types, according to Turatto (2000, *dashed*) and from the catalogue used in this work (*solid*); the agreement is fair for S0-Sb and later than Sdm types, and satisfactory for Sbc-Sd galaxies, although the uncertainties are much higher in the case of Turatto (2000); this is due to the fact that he evaluates SN subtype *frequencies* (and thus requires control exposure times, with associated uncertainties), while we take only subtype *ratios*.

in galaxy studies. We only plot those ratios in Fig. 4b as a consistency check of our results with those of previous surveys. On the other hand, Cappellaro et al. (1999) have shown that the frequencies of core collapse supernovae (II+Ib,c) depend significantly on the galaxy's $U-V$ colour, in the sense that higher frequencies correspond to smaller $U-V$ values, i.e. to younger galaxies; they suggested that this dependence reflects directly the dependence of the core collapse SN rate on the current star formation rate. If confirmed, this finding would allow then to probe the star formation rates of late type galaxies, i.e. their current status (provided that the relevant uncertainties, that is the effect of extinction on U-V indices, are adequately taken into account).

We suggest here that instead of SN frequencies, *ratios* between subtypes of core collapse supernovae could be used as a probe of the metallicity of the host galaxies, which is a measure of the integrated star formation activity of the galaxy, i.e. of its *past history*. Measurements of numbers of SN subtypes at higher redshifts would then allow to probe in much greater detail the history of metallicity evolution in the Universe. For that purpose, it would not be sufficient to simply plot the $N_{\rm Ib,c}/N_{\rm II}$ ratio as a function of redshift (as in e.g. Heger et al. 2003a). A detailed survey, equivalent to the one presented in Fig. 2, would be necessary: plotting the $N_{\rm Ib,c}/N_{\rm II}$ ratio as a function of the (rest frame) blue magnitude of galaxies at different redshifts, would enable us to check whether the variation of that ratio with blue magnitude was the same in the past; since this relationship is an indirect one (i.e via the metallicity of the host galaxy), such a survey would offer also clues about the metallicity-luminosity relation in the past.

Such a detailed survey would be possible with future instruments, such as the SNAP satellite (see web page at: `http://snap.lbl.gov/`). SNAP is expected to detect ~2000 SNIa up to redshifts of 1.7. Taking into account that core collapse supernovae are fainter (by ~two magnitudes) than SNIa and 2–3 times as frequent, one sees that SNAP will be able to construct large enough samples for the purposes of the proposed study at several redshift ranges up to $z\sim 1$.

5. Summary

This work explores (some of) the consequences of metallicity dependent mass loss of massive stars on the statistics of core collapse supernovae of various subtypes, and in particular on the ratio of type Ib,c vs. type II supernovae. According to current models of massive stars, this ratio should increase with increasing metallicity (Heger et al. 2003a). The exact form of that relationship depends (a little) on the adopted stellar IMF and mostly on the value of $M_{\rm Ib,c}$, the minimal value of initial mass for a star to explode as SNIb,c.

We show first that the observed $N_{\rm Ib,c}/N_{\rm II}$ does indeed display a metallicity dependence. For that purpose we construct a statistically significant sample of Ib,c and II supernovae as a function of their host galaxy's blue magnitude and we use the well-known metallicity-luminosity relation for late type galaxies (Garnett 2002).

However, the observed $N_{\rm Ib,c}/N_{\rm II}$ vs. Z relationship is steeper than theoretically expected, if one adopts non-rotating star models (from e.g. Heger et al. 2003a or Meynet & Maeder 2003). We argue that neither the assumptions of a metallicity dependent IMF or of an enhanced fraction of Ib,c supernovae originating in binary systems offer viable solutions to the problem. We suggest that rotating stellar models with mass loss, such as those recently calculated by Meynet & Maeder (2003) offer a much better quantitative explanation. We base our argument on models of solar initial metallicity and we urge calculations at lower *and* higher than solar metallicities in order to substantiate our conclusions.

Furthermore, we suggest that surveys of core collapse supernovae with the SNAP satellite will allow to probe the effect of metallicity on supernovae properties during a large fraction of the past history of the Universe, at least up to redshift $z\sim 1$.

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References

Baraffe, I., Heger, A., & Woosley, S. 2001, ApJ, 550, 890
Barbon, R., Buondí, V., Cappellaro, E., & Turatto, M. 1999, A&AS, 139, 531
Boissier, S., Boselli, A., Prantzos, N., & Gavazzi, G. 2001, MNRAS, 321, 733
Bressan, A., Della Valle, M., & Marziani, P. 2002, MNRAS, 331, L25
Cappellaro, E., Evans, R., & Turatto, M. 1999, A&A, 351, 459
Chiosi, C., & Maeder, A. 1986, ARA&A, 24, 329
Dekel, A., & Silk, J. 1986, ApJ, 303, 39
Ferreras, I., & Silk, J. 2001, ApJ, 557, 165
Foellmi, C., Moffat, A., & Guerrero, M. 2003a, MNRAS, 338, 360
Foellmi, C., Moffat, A., & Guerrero, M. 2003b, MNRAS, 338, 389
Garnett 2003, XIII Canary Islands Winter School on Astrophysics, in press [`astro-ph/0211148`]
Hamuy, M. 2003, in Core Collapse of Massive Stars, ed. C. L. Fryer (Dordrecht: Kluwer), in press [`astro-ph/0301006`]
Heger, A., Fryer, C., Woosley, S., Langer, N., & Hartmann, D. 2003a, ApJ, in press [`astro-ph/0212469`]
Heger, A., Woosley, S., Langer, N., & Spruit, H. 2003b, in Stellar Rotation, Proc. IAU Symp., 215, in press [`astro-ph/0301374`]
Heydari-Malayeri, M. 2003, in Massive stars, ed. J. P. Zahn, & M. Heydari-Malayeri (EDP Sciences), in press
Janka, H.-T., Buras, R., Kifonidis, K., Rampp, M., & Plewa, T. 2002, in Core Collapse of Massive Stars, ed. C. L. Fryer (Dordrecht: Kluwer), in press [`astro-ph/0212314`]
Kroupa, P. 2002, Science, 295, 82
Kroupa, P., Tout, C., & Gilmore, G. 1993, MNRAS, 262, 545
Maeder, A. 1992, A&A, 264, 105
Maeder, A., & Meynet, G. 1994, A&A, 287, 803
Maeder, A., & Meynet, G. 2002, ARA&A, 38, 143
Meynet, G., & Maeder, A. 2003, A&A, submitted
Mowlavi, N., Schaerer, D., Meynet, G., et al. 1998, A&AS, 128, 471
Nakamura, F., & Umemura, M. 2001, ApJ, 518, 19
Smartt, S., Maund, J., Gilmore, G., et al. 2003, MNRAS, in press [`astro-ph/0301324`]
Turatto, M. 2000, in The Evolution of the Milky Way, ed. F. Matteucci, & F. Giovanelli (Dordrecht: Kluwer), 361