Topical Astrophysical Problems on Massive Stars for VLT Observations

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1. Introduction

According to current wisdom, luminous matter represents only about one per cent of the mass in the Universe. Among this one per cent, massive O and B stars contribute to about two thirds of the optical light of galaxies and thus play a key role in the exploration of the visible universe with the VLT. Their high luminosities make them visible at large distances, either individually or by spectral features in the integrated spectrum of galaxies. Let us note that if one assumes for the VLT a limiting magnitude $\ell \sim 28.5$ (for S/N ~ 2 in 10 hours, see Fusi Pecci et al., 1994), then 25 $M_\odot$ stars will be detected up to distances superior to ~70 Mpc, a value which shows how large the volume is where massive stars can be observed. Massive stars are the main sources of UV and ionising radiation, also they power the far-IR luminosities of galaxies through the heating of dust. Due to these properties and their short lifetimes, massive stars are conspicuous tracers of star formation at large distance in the Universe.

Massive stars so much modify the physical conditions and the dynamics of the ambient interstellar medium that they influence the process of star formation in galaxies. In addition to radiation, massive stars are also the main source of mechanical power in galaxies due to supernova explosions and to the winds of Wolf-Rayet (WR) stars, which on the whole are of comparable importance. Massive stars with $M \geq 10\ M_\odot$ are fast nuclear reactors, they are thus the main contributors to the nucleosynthesis of heavy elements and also play a leading role in the chemical evolution of galaxies. Thanks to its high imaging and spectroscopic capacities, the VLT will allow us to observe massive stars and their effects in new distant environments, like early evolution of galaxies, starbursts, galactic nuclei and star formation processes around quasars.

A major change has occurred in our understanding of massive star evolution in the last 10 years. The point is that these stars nearly fully evaporate during their evolution. As an example, an initial 60 $M_\odot$ star of solar composition will only host about 5 $M_\odot$ at the time of supernova explosion (cf. Maeder and Conti, 1994). This evaporation is due to the stellar winds in the various phases, OB stars, supergiants and WR stars. Such low final masses are well supported by the WR luminosities and by the study of WR masses, and they have major consequences for all stellar properties: lifetimes, luminosities, evolutionary links, wind compositions, chemical evolution, supernova progenitors and the nature of final remnants.

2. A Remarkable Case: The Populations of Massive Stars in Starbursts

Starbursts are giant events of star formation in galaxies, they may involve regions with masses as large as 10^5 the Orion Nebula (cf. Kennicutt, 1984; Leitherer, 1991). Classic H II regions like the Orion Nebula contain only a few ionising stars and have a total mass of several tens of solar masses, while giant H II regions, like 30 Dor, have about 300 to 400 ionising O stars and a total mass of about 6 10^5 $M_\odot$. They are even dwarfed by starburst galaxies, like M82, Arp 220, NGC 6240, NGC 7714 where the total mass involved in the burst is a few 10^8 $M_\odot$. The luminosity associated to starbursts, like in M82, is as large as 7 $10^{10} L_\odot$ (cf. Rieke 1991). Such a value leads to important "evolutionary corrections" on the luminosity of distant galaxies and we need to correctly appreciate the frequencies and intensities of the starburst phenomena, especially at large redshifts, through the Universe both for cosmological reasons and for the study of the early evolution of galaxies.

Fortunately, there are several observable signatures of starbursts: the UV light, the nebular lines, the Hα emission, the He II 4686 emission line, the far-IR emission, the CO line, etc. Even when a galaxy cannot be resolved into stars, it is possible to learn about several properties of massive star populations (cf. Kunth and Sargent 1981; Arnault et al. 1989; Vacca and Conti 1992). Indeed, the flux of the Hα or Hβ lines in the integrated spectrum of a starburst provides an estimate of the total number N_{Lyc} of Lyman continuum photons, and N_{Lyc} indicates the number of present O stars. Typically, an O7V star provides 10^{49} Lyman photons per second. Refinements of this figure according to metallicity, upper mass limit and initial mass function (IMF) slope are feasible. The number of WR stars, when present, can also be inferred from the integrated spectrum; the broad emission line He II 4686 of WR stars remains visible with an equivalent width of a few Å despite the large dilution effect by billions of other stars. In particular, the ratio of the late WN stars (WNL) to the number of O stars is measured by the ratio of He II 4686/Hβ. Even further, the ratio of WN to WC stars (i.e. of those stars exhibiting products of CNO burning to those with products of He burning) can be estimated from the ratio of the He II 4686 to CIII/IV 4650 lines. A test of this method has been performed by Vacca (1991) using 30 Dor in the LMC. The number of O stars in a field of $7' \times 7'$ centred on R136 was found to be about 400 (cf. Parker and Garmany 1993). The analysis of the spectral lines in an integrated trailed spectrophotometric exposure of about the same area led to an estimate of some 330 O stars, a result which inspires a certain confidence in this procedure (cf. Vacca and Conti, 1992).

Such line ratios, which give in turn ratios of star numbers, are extremely informative on the properties of starbursts, like the star formation rate (SFR), the age and duration of the starbursts, the IMF and the metallicity Z. Generally, a higher Z leads to higher mass-loss rates for OB stars and supergiants, since there are more spectral lines and thus more momentum transferred by radiation. These higher mass-loss rates generally lead to larger numbers of WR stars at higher metallicities (cf. Maeder and Meynet, 1994). The critical line ratios will be observable in distant galaxies with the VLT, they will provide very useful information on the process of star formation through the history of the Universe. Also, we may hope that further spectral features containing information on other kinds of luminous stars like AGB stars, red supergiants, LBV, etc. will become accessible with VLT observations. All these features should be intensively searched for and studied, and the infrared spectra from the VLT might be particularly useful for this purpose.

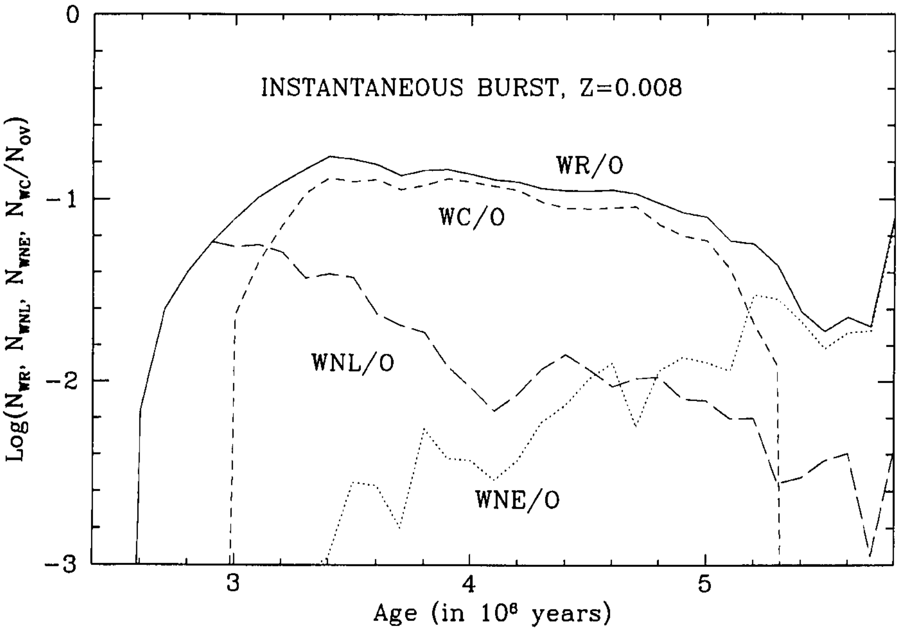


Figure 1: Evolution as a function of time of the number of WR, WNL (late WN), WNE (early WN) and WC stars divided by the number of O-type stars in the case of an instantaneous burst occurring at time t = 0. The stellar models used are those of Meynet et al. (1994) for Z = 0.008. The IMF used is dN/dM $\propto M^{-2}$.}

3. SFR, IMF, Age, Duration and Metallicity in Starbursts

One big hope for future observations of massive stars with the VLT is to disentangle the various parameters characterising the starbursts. As a first example let us examine the didactical, but not unrealistic case of an instantaneous starburst. According to recent models (cf. Maeder and Conti, 1994; Meynet, 1995) we may distinguish four different epochs in the initial evolution of a starburst (see also Fig. 1)

1. *O phase:* for an age $t \leq 2$ Myr, only O stars are present, giving rise to H II regions without WR features.
2. *WNL phase:* from t = 2 to 3 Myr, a large number of WNL stars are present.
3. *WN and WC phase:* from t = 3 to 7 Myr, the various subtypes of WR stars (WNL, WNE, WC) coexist with fractions depending on mass loss and metallicity Z.
4. *Late O phase:* for $t \geq 7$ Myr, WR stars have disappeared, but up to 10 Myr there are still O stars. They produce H II regions with nebular emission lines, but the equivalent width of the Hβ line for example should be much smaller than for the early O phase.

It has to be noted that the ratio WNL/O is much larger in a starburst (up to 6 times for solar Z) than in the case of constant SFR (see also Fig. 2), where there is always an equilibrium between stars entring and leaving the WR stage. Surprisingly also, if an observed H II region consists of a burst plus a region of lower but constant SFR, we shall observe over the 2 Myr after the burst a much lower WR/O ratio than in the case of constant SFR, since at this time the WR stars from the burst have not yet appeared. From the information provided by the WNL/O and WN/WC ratios we can make an estimate of the age of the burst and put some bounds on its duration in a given area. These number ratios are also sensitive to the slope of the IMF for a given metallicity Z.

An interesting application, which should be extended in future to more distant galaxies, is that of H II or WR galaxies (cf. Kunth and Sargent, 1983; Conti, 1991a); these are emission-line galaxies which show a broad emission feature at He II 4686. This line is also often shown by AGN's, but in WR galaxies the nebular lines are narrow, as caused by stellar ionising radiation in giant H II regions. Some of these WR galaxies show signs of collisions, mergers, jets, some are double, one is an IRAS galaxy. These H II or WR galaxies generally show, as derived from the line ratios, large excesses of WR stars with respect to O stars; Figure 2 shows the model predictions by Maeder and Meynet (1994) and Meynet (1995) compared to the observations by Vacca and Conti (1992); see also Maeder and Conti (1994). Burst models with two different IMF slopes are shown, where the IMF is defined by dN/dM = AM ($^{\Gamma-1}$). Figure 2 shows that the observed WNL/O ratios in these starburst galaxies are above the predictions for constant SFR and in nice agreement with burst models. The uncertainties are for now probably too large to enable us to infer Γ values for starburst regions. In this context it might be worth recalling that comparisons of clusters in the SMC, LMC and the Galaxy show no systematic change of G with metallicity Z, but the possibility that G is influenced by the intensity of the SFR is not unlikely (cf. also Scalo, 1989).

These examples illustrate the high potentialities of future spectroscopic studies on massive stars with the VLT. But further information could also be obtained from other lines, for example the Si IV and C IV UV lines in O stars (cf. Leitherer and Lamers, 1991; Mas-Hesse and Kunth, 1991) or from far-IR emission by the dust in H II regions. HST observations at λ 2200 of the WR galaxy He 2–10 by Conti (1994) reveal knots of intense star formation. The application of the method mentioned above for estimating the mass and age of the knots has led these authors to the fascinating result that one is just observing globular clusters at birth in this galaxy, since these knots have a mass of a few $10^5\ M_\odot$ and ages certainly below 10^7 years.

A prerequisite before interpreting any observation of massive stars in distant galaxies is that the models well apply to the Milky Way and to nearby galaxies. It is well known that large differences in massive star populations exist which can be interpreted by means of stellar models (cf. Maeder and Meynet, 1994). For example, the number ratios WR/O and WC/WN differ by factors 10 and 20 respectively between the SMC and inner regions of the Milky Way or of M31. Comparisons have shown that these large differences could be accounted for by metallicity effects which enhance the mass-loss rates and in turn influence stellar evolution.

4. SN-Dominated Galaxies and Nucleosynthesis

An interesting result of starburst models to be explored is that there should be a phase dominated by supernova (SN) explosions in the subsequent life of a starburst. A rule of thumb (cf. Meynet, 1995) is that one should have about one SN per century for the birth of 13,500 O-type stars. Applying this to the powerful starbust galaxy NGC 1614 in the list of Vacca and Conti (1992) one could expect about 12 SN per century. In the extreme case of the IRAS galaxy 01003–2238 (Armus et al., 1989) one would have about 45 SN per century. Do we observe such "SN galaxies" in a consistent way with existing starbursts? If not, why? If yes, the effects of such extreme situations on the interstellar medium and on the chemical enrichment of galaxies are fascinating topics about which almost nothing is known at the present time.

The chemical evolution due to starbursts is also an unexplored subject.

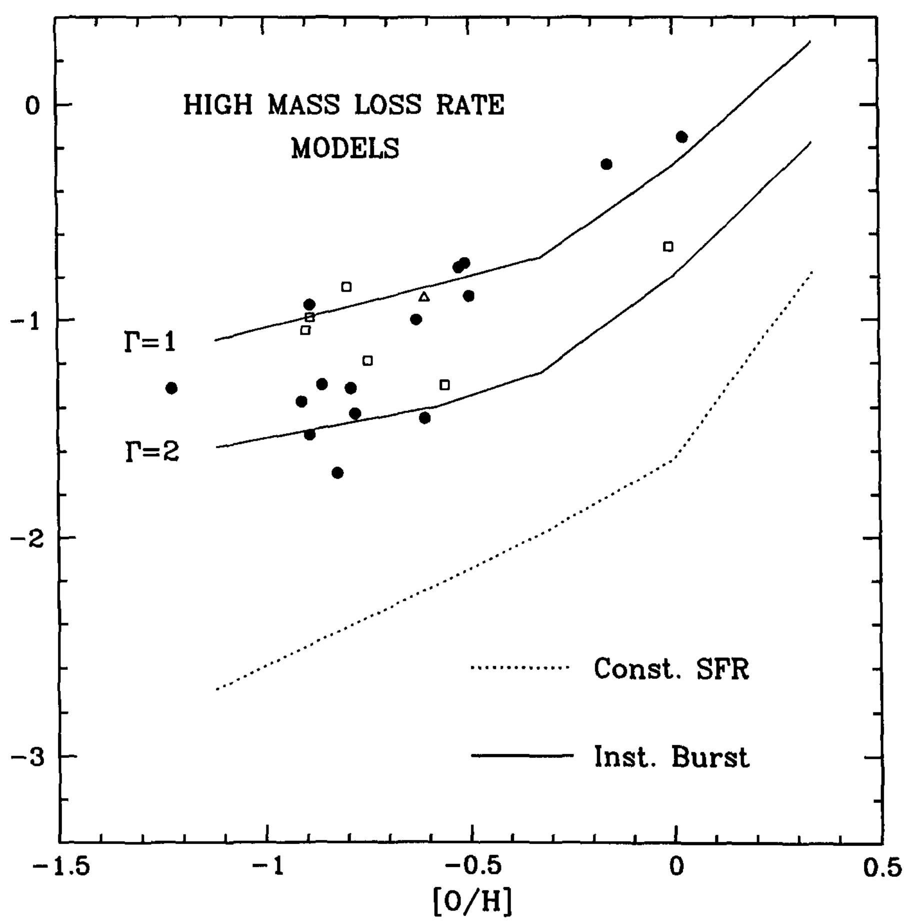


Figure 2: Relative number of WNL to O-type stars as a function of the relative abundance of oxygen expressed in terms of [O/H]. Filled circles are observed values as given by Vacca and Conti (1992). The open triangle represents 30 Doradus (from Vacca 1991) and open boxes are observations from Vacca as reported by Conti (1994). The dotted line presents theoretical values obtained in the case of a constant star formation rate with an IMF, $dN/dM \propto M^{\Gamma-1}$, with $\Gamma = -2$. The continuous lines are the predictions for an instantaneous burst with $\Gamma = -2$ and $\Gamma = -1$ (see Maeder and Conti, 1994; Meynet, 1995). Salpeter's value is $\Gamma = -1.35$.

High-resolution spectroscopy from the VLT could bring a lot of new information. The key effect in the interpretation of past chemical abundances rests on the fact that massive stars have short lifetimes. In the early phases of galactic evolution, only massive stars contribute to the chemical enrichment due to their short lifetimes. As time goes by, smaller stellar masses come into the game: firstly, only SNII contribute to the chemical enrichment (mainly in O, Ne–Ca elements and r-process elements), then appears the production of the intermediate-mass stars (with mainly C, N and s-process elements); they are followed by the contributions from supernovae SNIa (mainly Fe injection). Thus the ages at which stars of a given mass release their nucleosynthetic production are generally considered as the major effect regarding the changes of stellar yields as a function of time (cf. Matteucci, 1991). One should, however, also take into account the fact that the chemical yields are changing with initial Z and may this way influence the picture of chemical evolution of galaxies (Maeder, 1992). A schematic sketch of the various interplays intervening in galactic evolution is given in Figure 3.

In the case of a starburst the chemical contribution of the burst is only that of massive stars above some limit which depends on the age of the starburst. These yields are thus different from the average yields, especially if starbursts have a top-heavy IMF.

It is interesting to note that the study of the chemical evolution of starbursts may also have some relevance to understanding some of the abundance ratios observed in QSO's and AGN's. Prominent lines of OVI, NV and CIV are seen in QSO's with redshifts as high as $z \simeq 5$ (cf. Schneider et al., 1991). Analyses of a large sample of QSO's (cf. Haman and Ferland, 1992) suggest a sizeable overabundance of N, implying metallicities of the order of or larger than the solar value. If this is true, we need a fast initial chemical enrichment and a vigorous star formation in order to account for these metallicities.

In conclusion we may say that whatever the central engine of QSO's may be, a major challenge for future VLT observations will be a better understanding of the nature and properties of the stellar populations responsible for the heavy elements in QSO's.

As already mentioned above, the understanding of these remote regions of the Universe requires a thorough study of the massive star populations in the Milky Way and in the galaxies of the Local Group. Many questions related to the massive star evolution remain to be solved, and in the last sections of this paper we shall discuss a few points related to stellar physics to which observations with the VLT could make substantial contributions.

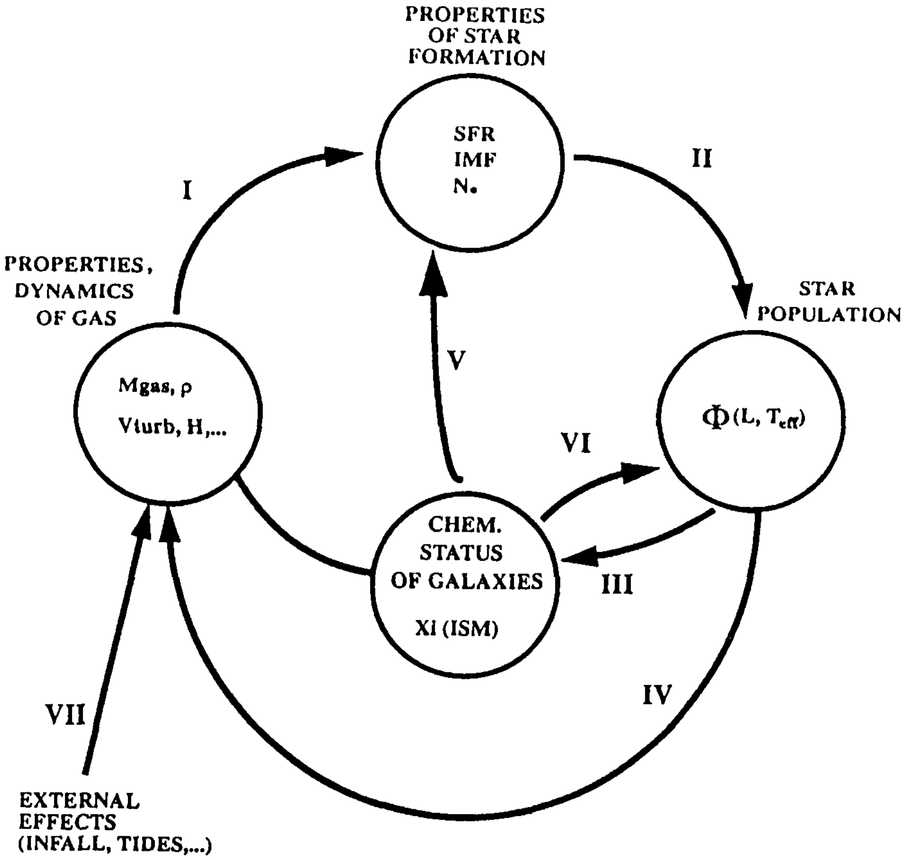
5. Massive Star Formation

According to Churchwell (1991), the formation process of massive O and B stars are very poorly understood. Theoretical models (Stahler, 1983; Palla and Stahler, 1992) show that accretion of matter during the pre-main-sequence phase plays a major role in determining both the evolutionary track followed during the formation process as well as the position and the structure of the star when it becomes optically visible. The apparent lack of stars more massive than about 40 $M_\odot$ in the vicinity of the theoretical ZAMS (Garmany et al., 1982; Massey et al., 1994) might be related to the fact that massive stars spend their entire pre-main-sequence lifetime and even probably the beginning of their H-burning phase, still enshrouded in the dusty molecular clouds out of which they formed.

The infrared facilities offered by the VLT will be of great help to reveal the structure of massive star nurseries. As an example, CO band absorption spectroscopy at 2.3 and 4.6 μm offers a powerful method of searching for conclusive evidences of gas infall in star forming clouds. The determination of temperature and luminosity function of young objects using multiband infrared imaging photometry will provide data to be compared with pre-MS stellar evolutionary tracks. The large VLT aperture will provide unprecedented high-resolution data. Its expected infrared resolution, with adaptative optics, of 0.06″ at 2 μm corresponds to 9 AU at the distance of the closest star-forming regions, i.e. Ophiucus Taurus. In view of these performances, the VLT will certainly reveal itself a powerful tool to investigate this still poorly known stage of massive star evolution.

6. Massive Stars in the Hertzsprung-Russel Diagram

The most recent HR diagrams for supergiants in the solar vicinity and in the LMC obtained by Blaha and Humphreys (189), Fitzpatrick and Garmany (1990)



I PHYSICS OF STAR FORMATION
II STAR EVOLUTION
III CHEMICAL YIELDS AND EVOLUTION
IV DEPOSITION OF MOMENTUM, ENERGY
V EFFECTS OF Xi ON IMF, SFR
VI EFFECTS OF Xi ON STAR EVOLUTION
VII EXTERNAL EFFECTS ON GAS DYNAMICS

Figure 3: *Schematic illustration of the interplay between star formation, stellar population, chemical and dynamical evolution of the interstellar medium.*

show a significant stellar population just on the red side of the main sequence ($\log T_{eff}$ = 3.9 to 4.1) for initial mass stars between 10 and 20 $M_\odot$. The presence of numerous stars in this part of the HR diagram is quite puzzling since, according to standard numerical simulations, evolution is quite rapid at this stage (blue Hertzsprung gap). Several different possible explanations have been proposed in terms of enhanced opacities (Nasi and Forieri, 1990), of scatter in mass-loss rates (Meynet et al., 1994), extended atmospheres and binaries (Tuchmann and Wheeler, 1989, 1990). Some incompleteness effects and problems of calibration relations between B–V and $\log T_{eff}$ may also be responsible for at least part of the problem. However, our feeling is that no good solution has been found yet and that new evolutionary tracks are needed to account for this important fact.

The number ratio of blue to red supergiants is an increasing function of the metallicity Z in galaxies, typically increasing by a factor of 10 from the SMC to the solar neighbourhood (cf. Humphreys and McElroy, 1984). Langer and Maeder (1995) showed that if, at a given metallicity, it is possible to account for the observed blue to red ratio, by changing the mass-loss rates or the mixing mechanism, no assumption on stellar model physics explored so far is able to cope with the general trend. All models do the opposite, i.e. many more red supergiants are predicted at high Z than at low Z. Langer and Maeder (1995) suggest some connection of the blue to red problem with internal mixing. Indeed they found that a restricted scheme for mixing (Ledoux) looks generally better at low Z, while an extended scheme might be better at high Z. The question is of course to know what is the physical mechanism producing this kind of behaviour.

7. Chemical Abundances at the Surface of Massive Stars

Very luminous and massive stars (which are of particular importance for extragalactic studies) are often too faint for detailed studies with existing telescopes (see Appenzeller, 1986). The great aperture of the VLT will enable us to obtain the high-resolution spectrograms ($R = \lambda/\Delta\lambda$ between 10^4 and 10^5) with high signal-to-noise ratios (S/N ~ 10^2 to 10^3) necessary to the measurement of reliable abundances at the surface of extremely bright stars in extragalactic systems of different chemical composition. These observations can then be used as standards for lower resolution studies of more distant stellar systems.

A lot of very interesting observational facts concerning the surface composition of massive stars have been collected in the past years. In particular, the recent finding of Herrero et al. (1992) that all fast rotators among O stars show surface He-enrichments is a very important result. It shows that rotationally induced mixing is strong enough to transport the newly-processed elements to the surface during a fraction of the main-sequence lifetime. This implies that all stellar properties are influenced by this effect: lifetimes, luminosities, nucleosynthesis, etc.

Walborn (1976, 1988) showed that ordinary OB supergiants have He- and N-enrichments as a result of CNO processing. Only the small group of peculiar OBC-stars have the normal cosmic abundance ratios (cf. also Howarth and Prinja, 1989; Herrero et al., 1992; Gies and Lambert, 1992). There are two alternatives to explain the He- and N enrichments in supergiants and both bring about new problems (Maeder, 1995).

(1) The first alternative is that blue supergiants are on the blue loops after a first red supergiant stage where dredge up has occurred producing the observed surface enrichments. The problems related to this hypothesis are the following: (a) At Z = 0.02, current grids of models (Arnett, 1991; Schaller et al., 1992; Alongi et al., 1993; Brocato and Castellani, 1993) only predict blue loops for masses equal to or lower than 15 $M_\odot$. At higher masses there are no blue loops and no predicted enrichments. (b) Even on the blue loops the predicted enrichments do not seem high enough to account for the observations.

(2) Another possibility is that the mixing responsible for the surface abundances of these supergiants occurred already on the main sequence. We may, for instance, assume that the

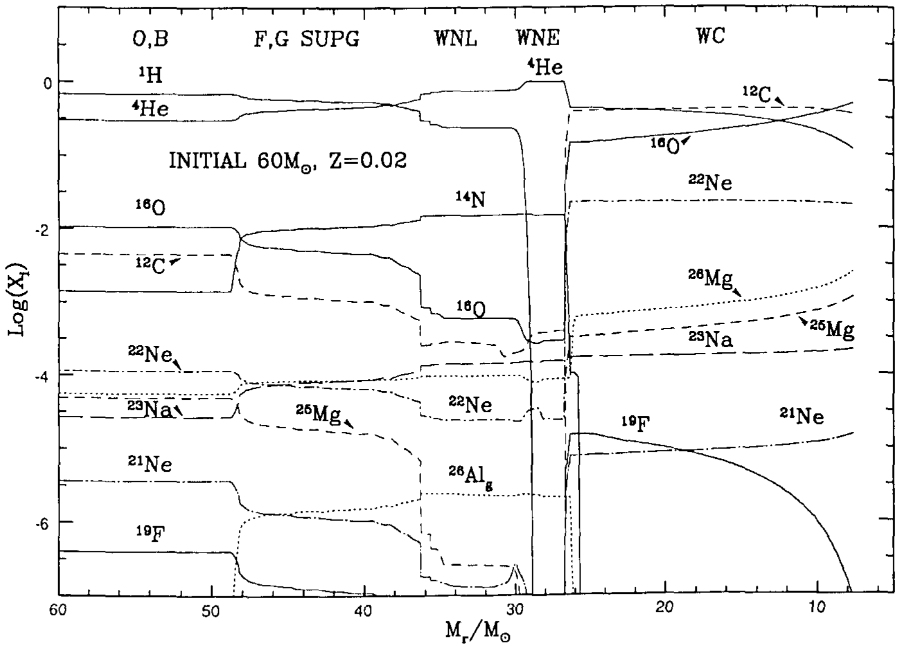


Figure 4: *Changes of surface abundances (in mass fraction) versus the remaining stellar mass in solar units for a 60 $M_\odot$ model with Z = 0.02. At the top, the corresponding evolutionary stages are indicated.*

effects producing enriched O stars (see above) are also active in lighter lower mass stars and that they lead to surface enrichments in supergiants resulting from a larger range of initial masses.

Whatever the solution, there is no doubt that, as for the problem of the blue to red supergiant ratio, mixing processes play a key role in understanding these observations.

8. Luminous Blue Variables and Wolf-Rayet Stars

Some of the most luminous stars have sporadic, violent mass-loss events whose causes are not understood. These evolved hot stars are called luminous blue variables (LBV) and their instability may shape the appearance of the upper HR diagram (Humphreys and Davidson, 1995; see also Maeder and Conti, 1994). Presently, these stars are interpreted as a short stage in the evolution of massive stars with initial masses $M > 40\ M_\odot$. A likely scenario is (cf. Maeder and Conti, 1994).

$$\text{O star} \rightarrow \text{Of/WN} \rightarrow \text{LBV} \rightarrow \text{Of/WN} \rightarrow \text{LBV} \ldots \rightarrow \text{WN} \rightarrow \text{WC}$$

Are these violent eruption stages responsible for some of the rings observed around WR stars? Marston et al. (1994) have found that of the 145 galactic WR now surveyed, more than a quarter have associated ring nebulae. Several WR are shown to be surrounded by multiple rings (2 or 3) which suggests the occurrence of multi-ejection stages as is thought to occur during the LBV phase. More observations are required to go ahead with this hypothesis.

Among the stars with extraordinary mass outflows, WR stars certainly occupy a first-rank position. These stars are nowadays considered as bare cores left over from massive stars by mass loss; however, the exact cause of this extreme mass loss is still unknown. Recent works have succeeded in explaining the large observed changes of the number ratios WR/O, WC/WN in galaxies of different metallicities (cf. Maeder and Meynet, 1994). These changes are due to the larger mass-loss rates at higher Z. Also, the models were able to explain the observed trend of WC9, WC8 and WC7 to be located in inner regions of the Galaxy.

The sequence of WR stars nicely corresponds to a sequence of more advanced chemical processing becoming visible at the stellar surfaces (see Fig. 4). The standard models (cf. Schaller et al., 1992) predict an abrupt transition from WN to WC stars, since the He core is growing and building up a steep chemical discontinuity at its outer edge. Thus the standard models predict almost no (< 1%) stars with intermediate characteristics of WN and WC stars. However, there are about 4% of such intermediate stars (Conti and Massey, 1989). It has been shown by Langer (1991) that a mild mixing like that produced by semiconvective diffusion can account for these stars. The existence of WN/WC stars undoubtedly shows that an extra-mixing process is at work, even during the short He-burning phases.

Except at very low metallicity, WC stars are expected to present very high level abundances of ^{22}Ne at their surface as a result of the transformation, at the beginning of the He-burning phase, of the ^{14}N left by the CNO cycle (Maeder, 1990). However, the infrared observations by Barlow et al. (1988), for the WC8 star γ-Vel give Ne/He = 0.005 (in mass fraction), i.e. at least 6 times less than predicted. (However, this is twice the solar ratio). Let us note that the issue of this problem does not only concern a detail of stellar structure but is also important for the nucleosynthesis of s process elements in massive stars, since the ^{22}Ne is the major neutron source in these stars. It has also some implications on the understanding of the high values for the isotopic ratio ^{22}Ne/^{20}Ne found in cosmic rays, which has been interpreted as the signature of a WR contribution (Maeder and Meynet, 1993).

At present, observations of mass loss, of ejected shells, of surface chemistry, of LBV and WR properties are rather scarce and much safer conclusions on the last stages of massive star evolution in galaxies of different metallicities are still very much needed.

9. The Supernova 1987A, Stellar Remnants

According to McCray (1993), the light curve of SN1987A, powered by ^{44}Ti decay (t_{44} = 78 yr), should remain steady around $m \simeq 19$ for decades and thus be quite well observable with the VLT. There is no doubt that this zone of the sky will reserve further surprises when studied with this powerful instrument. First of all one could be able to test the hypothesis of the presence of a companion. Indeed, some authors (Soker and Livio, 1990; Podsiadlowski, 1992) have invoked the possibility that Sk–69 202 was a binary. If not disrupted by the explosion, its mass must be inferior to 2.5 $M_\odot$, otherwise we should see its light in the optical continuum. Another very interesting question will be to know what kind of remnant this explosion has left, a neutron star or a black hole? An optical pulsar might be detected (with $m_V \leq 23$) if it has a luminosity $L_{opt} \geq 3 \times 10^{34}$ ergs^{s-1} (McCray, 1993). It is also expected that when the supernova ejecta will interact with matter expelled by the progenitor, very spectacular outputs will be produced. Luo et al. (1993) estimate that a shock will strike the ring of matter which surrounds the supernova at a radial distance of ~ 0.7 lt-yr, in 2004 ± 3. At that time, strong radio, optical and UV emissions are predicted to occur (Luo and McCray, 1991; Suzuki et al. 1993; Luo et al., 1992). After the initial impact, the ring will become a bright source of soft X-rays and infrared continuum.

The importance of the mass limits for neutron stars and black holes for the chemical evolution of Galaxies has been recently discussed by Maeder (1992).

The yields in heavy elements strongly decrease with the lowering of M_{BH}, the lowest mass limit for black hole formation, since then more heavy elements are swallowed by black holes. Comparisons with observational data, in particular with the DY/ DZ ratio suggest a value of M_{BH} around 20 or 25 $M_{\odot}$. The dependence of the yields and supernovae types on metallicity and on the value of M_{BH} is a key problem in stellar astrophysics with many implications. Much theoretical and observational work is still needed in this area.

10. Massive Stars in Galaxies as Distance Indicators

As already emphasized above, massive stars are fantastic tools to explore the remote universe. The VLT will be able to observe long-period Cepheids up to a distance of 70 Mpc and red supergiants up to 700 Mpc. Type Ia supernovae will be detected up to 7000 Mpc (Moorwood, 1986).

Cepheids, because of their importance in the determination of the cosmological distance scale, deserve particular attention (cf. the recent detections of Cepheids in galaxies of the Virgo cluster by Pierce et al., 1994, Freedman et al., 1994, Saha et al., 1995). Since different modes of pulsation follow different period-luminosity relations, it is crucial to obtain accurate distances to be able to discriminate between these modes. The effects of the chemical composition has also to be fully understood. In this context it is interesting to emphasize that the Cepheid models predict different surface He-contents and N/C ratios according to metallicity Z and masses (cf. Schaller et al. 1992). The difference in helium content, $Y_s = 0.243$ at $Z = 0.001$ compared to $Y_s = 0.33$ at $Z = 0.020$, should have some consequences for the driving mechanism and thus for the amplitudes of Cepheid pulsations at different Z. Such differences of amplitude distributions between Galaxy, LMC and SMC are known to exist (cf. van Genderen, 1978) and we may suspect a relation with the different helium contents.

The possibility for the VLT to perform infrared observations will also be important in this context. Indeed, in addition to the fact that, in the infrared, the standard distance indicators are subject to much lower extinction uncertainties than in the visible, Cepheids, in this wavelength range, exhibit a tighter period-luminosity relationship which is less metallicity-dependent (Moorwood, 1986).

11. Conclusion

A universe without massive stars would be nearly a dead universe with such long evolutionary time scales that it would appear quite unevolving. Indeed, even if massive stars are quite rare objects, they are nevertheless the main engine of many active processes, as stated in the introduction. Their role in the study of star formation and evolution of galaxies, as well as the many problems which still need to be clarified on their internal and external physics, make massive stars first-rank goals for VLT observations.

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