THEORETICAL EVOLUTION OF MASSIVE STARS WITH MASS LOSS BY STELLAR WIND.

C. Chiosi, E. Nasi[†], G. Bertelli[*]
Istituto di Astronomia di Padova
† Osservatorio Astronomico di Padova, and Istituto di
Astronomia di Bologna
* Unità di Ricerca G.N.A./C.N.R. di Asiago-Padova

INTRODUCTION

Although it was known since a long time that very lumi-
nous blue and red stars may show evidence of mass outflow,
it was the advent of the Copernicus satellite that clearly
ascertained all OB supergiants (and also the most luminous
main sequence stars) are losing mass at rates that are signi-
ficant for their evolutionary history. The observational in-
formation for blue luminous stars (O, Of and WR) has been re-
cently reviewed by Conti (1978), who discussed in some detail
the data available for different spectral regions. The rates
of mass loss inferred from these observations are estimated
to be in the range 10^{-7} to 10^{-5} $M_\odot$/yr for OB stars, and from
10^{-5} to 10^{-4} $M_\odot$/yr for WR stars. Several theoretical models
have been proposed to explain those high mass-loss rates, and
the high terminal velocities ranging from 1000 to 3000 km/sec.
The two basic models are: the cool radiation pressure model,
originally proposed by Lucy and Solomon (1970) and elaborated
by Castor et al. (1975), in which the envelope is accelerated
by momentum transfer from radiation to ions due to the ultra-
violet line absorption; and the coronal model of Thomas
(1973), and Hearn (1975), where the wind is sustained by gas
pressure in a hot corona around the star. As both models do
not completely account for the observations, several comple-
mentary modifications have been suggested. The nowaday si-
tuation is reviewed by Cassinelli and Lamers (1978), and Con-
ti (1978).

On the side of red supergiants, both the observational
and theoretical understanding of mass loss phenomenon unfor-
tunately have not yet received the detailed systematic scru-
tiny afforded for luminous OB stars. The presence of circum-
stellar absorption lines in the spectra of cool stars is cu-
stomarily thought of as indicator of mass outflow.

For lack of knowledge about the specific mechanism re-
sponsible of the mass loss, empirical mass-loss rates have

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been estimated, Reimers (1975). However, the many uncertain-
ties involved in the transformation of a circumstellar line
profile into a mass-loss rate are such that the current esti
mates for particular stars may differ by order of magnitude,
Bernat (1977).
     Amongst the others, one possible mechanism was suggest-
ed by Fusi-Pecci and Renzini (1975), who supposed the wind
be originated by a hot corona produced by a non thermal pro-
cess, such as the dissipation of the acoustic energy genera-
ted in the outer convective envelope.
     The effect of mass loss, whatever might be the specific
mechanism, on the evolutionary history of massive stars was
argument of several independent theoretical investigations,
Chiosi and Nasi (1974), Chiosi et al. (1978a,b), Czerny
(1978), Dearborn et al. (1978), de Loore et al. (1977a,b).
Most of these computations are limited to the central and
shell H-burning, whereas only one attempt was made to follow
the model evolution up and through the core He-burning. For
lack of a completely satisfactory theory of mass loss in all
evolutionary phases, semiempirical and parametrized approa-
ches were adopted, and sequences of models whose mass simply
decreases with time were computed. As long as the occurrence
of mass loss is taken into account by such a hydrostatic
treatment, the model computations are roughly equivalent even
though different specific analytical relations for the mass-
loss rate are adopted. Nevertheless, the sensitivity of the
evolutionary results to the total amount of mass removed from
the models during a given phase rises the problem of the con
sistency of the mass-loss rate with the evolutionary phase
under consideration. This is particularly true when semiempi
rical mass-loss rates, inferred from the observational data,
are used in computing the models. As an example of this, the
adoption of mass loss rates for supergiant stars, presumably
in a post main sequence stage, to compute losing mass models
in central H-burning would certainly lead to overestimate
the amount of mass lost during this phase.
     In this note we will discuss the results of Chiosi et
al. (1978a,b), and perform a comparison with those of other
authors. Moreover, by comparing the general features of the
HR diagram of luminous OB stars we try to put lower and up-
per limits to the mass-loss rate that has to be used in the
model computations. The estimated mass-loss rate is confined
within a range much narrower than the observational uncer-
tainty. Finally we outline the current theoretical understan
ding about the evolutionary status of the transition WR, Con
ti (1976), and cast some light on the possibility that sin-
gle stars might become single WR stars.

1. DESCRIPTION OF THE EVOLUTIONARY RESULTS

Since quite exhaustive descriptions of the results about evolutionary models incorporating mass loss already exist in the literature, in the discussion below we will report only on the most salient points.

In the model calculations of Chiosi et al. (1978a,b) the mass-loss rate was calculated from one of the three relations. At high effective temperature the evolutionary sequences were calculated using rates based on the theoretical study of Castor et al. (1975)

$$\frac{dM}{dt} = \frac{L}{cv_{th}} \; \frac{\alpha}{\Gamma} \; \left[\frac{1-\alpha}{1-\Gamma}\right]^{\frac{1-\alpha}{\alpha}} \; (K\Gamma)^{1/\alpha} \qquad (1)$$

where the symbols have their usual meaning, α was taken as an adjustable parameter varying from 0.76 to 0.90, Chiosi et al. (1978a). In the same range of effective temperature, Chiosi et al. (1978b) adopted a mass-loss rate based on the empirical formulation of Barlow and Cohen (1977)

$$\frac{dM}{dt} = a(L/L_{\odot})^{b} \qquad (2)$$

Two choices for a have been explored, namely a=6.8 10^{-13} $M_{\odot}$/yr and two times this value, b was kept fixed and equal to 1.10. It is evident that the mass-loss rate of O stars of Barlow and Cohen (1977) was adopted. At low effective temperature, roughly below 3.8 in the logarithm, the mass-loss rate adopted by Chiosi et al. (1978a) is based on the theoretical suggestion of Fusi-Pecci and Renzini (1975) of an acoustically driven wind. The rate is given by

$$\frac{dM}{dt} = \epsilon \; \frac{L_{ac}}{v_{esc} \, v_{s}} \qquad (3)$$

which is based on the momentum conservation. In the above relation L_{ac} is the acoustic luminosity in solar units, v_{esc} and v_{s} are the escape and sound velocities respectively, ϵ is a free parameter (10^{-4}), Chiosi et al. (1978a). It must be said that the rates actually used in the computations were larger than those estimated by Reimers (1975) for less luminous (massive) stars, although close to the recent evaluation of Bernat (1977). Semiconvection during core H-burning, shell H-burning, and He-burning was taken into account adopting the Schwarschild and Härm (1958) condition ($\nabla_{R}=\nabla_{a}$). More details about the input physics and the computational procedure are in Chiosi et al. (1978a) and references quoted the-

rein. Several sets of evolutionary sequences were computed
for models of initial mass in the range 20 $M_\odot$ to 100 $M_\odot$ and
with Pop I initial chemical composition (X=0.700, Z=0.02).
All of them cover the core and shell H-burning phases, but
with different laws for the mass-loss rate, either (1) or
(2), while only three evolutionary sequences (20, 40, 80 $M_\odot$
of initial mass, and mass-loss rate given by eq. (1) with
α=0.9) were carried through the acoustic flux driven wind re
gime for explorative purposes.

1.1. The HR Diagram of the Core H-Burning Models

Several novel features of the HR diagram of massive
stars undergoing mass loss are evident by comparison with the
evolutionary sequences at constant mass. With moderate mass-
loss rates (10^{-7} $M_\odot$/yr for a 20 $M_\odot$ to 5 10^{-6} $M_\odot$/yr for a 100
$M_\odot$/yr on the main sequence), the core H-burning models are
less luminous than they would have been without mass loss,
and cover a wider range of effective temperature. With slight
ly larger mass-loss rates the most massive stars, approxima-
tely from 60 $M_\odot$ to 100 $M_\odot$, invert their path in the HR dia-
gram, and long before the central H-exhaustion stage shrink
towards the main sequence. This fact is mostly due to the
lowering of the opacity in the outer layers when He-rich CNO
processed material is brought to the surface by mass loss.
This behaviour of the evolutionary sequences leads to quite
a natural explanation of the observed upper boundary of the
luminosity of OB supergiants, decreasing with decreasing ef-
fective temperature , Hutchings (1976), Snow and Morton (1976).
It goes without saying that owing to the very short time sca
le of the shell H-burning phase, the area of highest observa
bility in the HR diagram is enclosed between the zero age
main sequence and the locus of lowest effective temperature
during the core H-burning phase. As those stars are very near
to the main sequence, the location of the standard occupation
area for core He-burning models in this range of mass (60 to
100 $M_\odot$) is too red to account them, Stothers and Chin (1976).
The discussion below will clarify that, even though in
contrast with the conservative evolution, the core He-burning
of losing mass models in this range of mass is found to take
place near the main sequence, the rather short lifetime can-
not account for the number of these stars which is comparable
to what it would have had on the basis of a standard initial
mass function. Moreover, the speculation is that core He-burn
ing models of this initial mass should not appear as O, Of
but rather as WN7 stars.

1.2. Internal Structure and Semiconvection

Several features of the internal structure of the core
H-burning models are worthy of mention because of their im-

plications on subsequent evolution. They are: the mass exten
sion of the semiconvective regions, the mass of the He core
existing at the time of the core He-ignition, the profile of
chemical composition throughout the models.

     As it was firstly noticed by Chiosi and Nasi (1974), and
later discussed to some extent by Chiosi et al. (1978a,b), no
ne of the evolutionary sequences computed taking into account
mass loss shows the presence of semiconvection during the en-
tire core H-burning phase. Semiconvection and full intermedia
te convection are restored later, although to a much less
extension than it would have occurred in constant mass models.
The analysis of Chiosi et al. (1978b) also clarifies that
mass-loss rates as low as those given by Barlow and Cohen
(1977) for O stars, likely constitute an upper limit for the
existence of semiconvection in massive stars. With the occur
rence of mass loss, the mass of the He core is significantly
smaller than for constant mass models, and decreases with in
creasing mass-loss rate. This result is relevant for the eva
luation of the yield of heavy elements per stellar genera-
tion and correlated galactic chemical evolution, Arnett (1978).
Adopting the new $M_\alpha(M.)$ relation for losing mass models, Chio
si and Caimmi (1978) and Chiosi (1978a) estimated a signifi-
cantly lower yield of heavy elements. It must be also empha-
sized that this result depends only on the occurrence of mass
loss during the main sequence phase, and is not fraught with
the many uncertainties inherent to mass loss during the red
phases.

1.3. The Problem of the Mass Determination

     In presence of mass loss the evolutionary tracks do not
coincide with lines of constant mass in the HR diagram, and
the current procedure of assigning the mass to a single star
by means of either a mass-luminosity relation or the use of
evolutionary tracks is no longer valid. This problem was di-
scussed to some extent by Chiosi et al. (1978a). No attempt
however was made to re-estimate the mass of individual stars
in the list of Snow and Morton (1976). The possibility of a
substantial difference between the actual mass of a star in
presence of mass loss and that it would have been assigned
by a standard procedure was taken into account by Abbott
(1978) discussing the relationship between the terminal and
the escape velocity. Amongst the others, the adoption of mo-
re realistic masses for stars undergoing mass loss revealed
that terminal velocities can be fitted by the empirical rela
tion $v_\infty \simeq 3v_{esc}$, in agreement with the predictions from the
theory of radiatively driven stellar winds of Castor et al.
(1975). Finally, Chiosi et al. (1978a) showed how the uncer-
tainty in the mass determination is not very severe for stars
close to the main sequence and of rather low mass, approxima
tely below initial 45 $M_\odot$, but can be as large as 40-50 % in

the case of the most luminous stars.

1.4. The Isochrones

The determination of the age of star clusters by means
of the isochrones in the HR diagram involves the bolometric
magnitude M_b and/or the spectral type Sp of the turn off
point of the core H-burning sequences, Barbaro and Chiosi
(1973). These two parameters are known to correlate primari-
ly with the age, and secondly to the initial chemical compo-
sition X and Z. The effect of mass loss is to lower the ages
for the same M_b and Sp and fixed chemical composition below
those allowed by constant mass evolution. This fact could
partially remove the well known discrepancy between the kine
matic expansion ages and nuclear ages (estimated from evolu-
tionary tracks).

1.5. The Generator Function of the Mass-Loss Rate

The comparison of the present results with those of other
authors, Czerny (1978), and de Loore (1977a,b) was performed
by Chiosi et al. (1978b). To this purpose several basic rela
tionships among fundamental variables $\left[Log <L/L_\odot> \sim Log <M> \right.$,
$Log(M_f/M_\odot) \sim Log <\dot{M}>$, and $Log\ t_H \sim Log <M> \left. \right]$ were constructed,
aimed to provide a theoretical network to which compare the
observations. Owing to   this, the area covered in the HR
diagram by losing mass models in core H-burning, the amount
of mass lost by the models during the core H-burning phase,
the variation of the core H-burning lifetime, and the surfa-
ce chemical abundance have been compared as functions of the
initial mass, mass-loss rate, and mass-loss rate relation.
This analysis allowed us to put plausible constraints on the
mass-loss rate and its dependence upon fundamental stellar
parameters to reproduce the observed distribution of losing
mass OB stars in the HR diagram. A good agreement is achieved
by models having mass-loss rates intermediate to those of the
set $\alpha=0.83$ and $\alpha=0.90$ of Chiosi et al. (1978a). The compari-
son of the theoretical rates to those inferred from the ob-
servations, Barlow and Cohen (1977),is made introducing the
concept of the generator function of the mass-loss rate de-
pendence. In fact, it goes without saying that rate and lu-
minosity of losing mass stars are conditioned by the occur-
rence of mass loss in their previous history. Hence the lumi
nosity to mass-loss rate dependence, such as suggested by the
observations, might be somewhat different from the one actual
ly involved in the mass loss process, and responsible of the
observed features. In virtue of this, and taking into account
that the maximum probability of observing a losing mass star
is expected at some intermediate stage of central H-burning,
Chiosi et al. (1978b) correlated the experimental rates of
Barlow and Cohen (1977) to theoretical values intermediate

between those of the sets α=0.83 and α=0.90 of Chiosi et al.
(1978a) when the mass-loss rate of ζ Pup is taken as a basic
constraint.

1.6. The Core He-Burning Phase

Three evolutionary sequences of the set α=0.90, namely
with initial masses 20, 40, 80 M$_\odot$ were continued through the
red stages in the HR diagram, taking into account mass loss
by acoustic flux mechanism of Fusi-Pecci and Renzini (1975),
and carried up to advanced stages of central He-burning,
which takes place at high effective temperature, Chiosi et
al. (1978a). Although the mass-loss rates of the acoustic
flux driven wind phase were higher than those extrapolated
from the empirical relation of Reimers (1975) for lower lumi
nosities, still the results below can be used as exploratory
indication of the effect of mass loss on core He-burning mo-
dels.

Current ideas about the problems of the core He-burning
phase of conservative evolution have been recently reviewed
by Chiosi (1978b). The location in the HR diagram of conser-
vative models in stationary central He-burning is known to
depend primarily upon the intermediate convective instabili-
ty through its effect on the chemical profile of the models,
and secondly on details of the input physics. In the case of
the Schwarzschild and Härm (1958) condition, the results can
be schematically described as follows. In the range of mass
20 to 40 M$_\odot$ the models ignite the central He-burning as blue
supergiants, slowly moving redwards in the HR diagram. Two
areas of stationary burning with nuclear time scale, can be
identified, blue and red separated by a yellow region of se-
cular instability, thermal time scale. The relative lifetime
spent in the blue and red stages is not unique with the stel
lar mass, but is known to depend also on several factors of
the input physics, Chiosi (1978b).

Models whose mass is greater than roughly 40 M$_\odot$ do not
show the blue phase, but after a rapid run toward low effec-
tive temperature regions spend the whole core He-burning as
red supergiants. This picture was understood mostly in terms
of the effect of the H-profile on the model location in the
HR diagram, Chiosi (1978b) and references quoted therein. The
occurrence of mass loss during core H and He-burning phases
somewhat affects the above schematization, and the models of
Chiosi et al. (1978a,b) allow to draw several preliminary re
marks.

Models with significant loss of mass during the core H-
burning phase, no matter of their initial mass, move redward
on a very short time scale. Further mass loss at high rate
($\sim 10^{-4}$ M$_\odot$/yr), via the specific mechanism of acoustic flux
driven wind in our computation, in the region of low effecti
ve temperature forces the models back into the blue supergiant

area. The bluewards movement seems to take place once the fractionary mass of the He core, M_{He}/M, gets larger than O.6, being the models still far from the thermal equilibrium condition. Hence the stationary He-burning in the core can initiate only after the models have reappeared as blue supergiants. Later on they slowly move to higher and higher effective temperature as the central He-content is burnt out. The fate of models with smaller mass-loss rate at low effective temperatures, being not yet computed is still unknown, although we might expect a qualitatively similar behaviour.

Moderate mass loss during the phase of central H-burning gives quite a different picture. Models with initial mass greater than $\sim$40 $M_\odot$ do not start the stationary central He-burning at high effective temperature, but on a short time scale move redward. Their subsequent evolution in presence of mass loss resembles to that of the previous case. On the contrary models with initial mass $\lesssim$40 $M_\odot$ have the stationary core He-burning as blue supergiants, while slowly moving redward. The phase of low effective temperature mass loss should be reached for these models in a very advanced stage of central He-burning. Their later evolution not yet computed is still uncertain.

We would like to outline as the most salient result of these computation the discriminatory effect of mass loss on the movement direction in the HR diagram for core He-burning models. Moderate mass loss (blue and red stages) causes the models in stationary central He-burning to move from blue to red. On the contrary high mass loss (blue and red stages) makes the models in stationary He-burning to move bluewards. The preliminary nature of these computations makes the core He-burning phase of losing mass models still fraught with many uncertainties, and demands a deeper investigation.

1.7. The Blue, Yellow and Red Supergiants

The comparison of the predicted zone of occupation for stars evolving at constant mass and in core He-burning phase with the experimental distribution of blue, yellow and red supergiants in the HR diagram was widely discussed by Stothers and Chin (1976), and references quoted therein. It was clear from that analysis that in the case of the Schwarzschild and Härm criterium the models were too cool compared with the bulk of blue stars, and also they predicted too many red supergiants of mass greater than 30 $M_\odot$. On the contrary, one of the most remarkable features of the HR diagram of supergiant stars in the galaxy is the lack of the very luminous red supergiants ($M_b \lesssim -8$). Stothers and Chin (1976) suggested that either different opacities or inclusion of mass loss in model computations could remove the above difficulties. Models of Chiosi et al. (1978a) showed that the core He-burning phase of losing mass models firstly covers a broader area of the HR

diagram, greatly improving the agreement with the observation,
secondly that stars more massive than 50 $M_\odot$ on the main sequen
ce, which suffer substantial mass loss during the core H-burn-
ing and later phases, do not reach the Hayashi line, thus ne-
ver becoming red supergiants. It is worth noticing that this
result is due to the effect of mass loss mostly during core
H-burning rather than later phases. Alhtough preliminary, the
se results lend some support to the idea that mass loss from
massive stars could actually be a clue to achieve a satisfac
tory understanding of the distribution of blue, yellow and
red supergiant stars in the HR diagram.

2. THE WR STARS

The majority of WR stars are known members of binary sy
stems, but whether or not they all are binaries is not yet
firmly established. The current theoretical understanding of
confirmed binary WR stars recognizes in the mass exchange pro
cess the mechanism responsible for producing a WR object al-
though many questions are still left unsolved. However, as a
number of well studied objects (e.g. HD 192163, HD 50896) has
no indication of binary nature, we must consider the possibi
lity that some of the WR stars are single objects and seek
other processes than mass exchange. Conti (1976) made the sug
gestion that O stars would become Of's if substantial wind we
re to exist. With increasing strength of the mass outflow,
Of's would transform into "transition WR stars". Later, if
further mass loss were still to occur, as suggested by the ob
servations, Conti (1978) and references quoted therein, the
transition WR's would evolve into classical WR stars. It is
evident that a temporal evolutionary sequence is suggested to
exist among O, Of and all WR types. The discussion below will
propose a slightly different picture which is perhaps able to
remove part of the difficulties present in Conti's (1976) sug
gestion. Reviews of the general properties of WR stars are by
Conti (1976) and Paczynski (1973). However a few basic points
are worth mentioning here, as they are relevant to our discus
sion. The position of WR stars in the HR diagram was discus-
sed by Conti (1976). The majority of WR's are located in the
box $-8 > M_b > -9$, $4.4 < \text{Log } T_e < 4.7$, (the bolometric corrections and
the color index-effective temperature scale may however intro
duce a considerable uncertainty), on the contrary, the transi
tion WR's otherwise classified as WN7/WN8 are clearly apart
from other subclasses as they are situated at higher lumino-
sities and have average hotter effective temperatures. As far
as the chemical composition of the surface is concerned, the-
re is little evidence of hydrogen in most WR's, the $N(H)/N(He)$
ratios being in the range 1.-2. for WN7/WN8 types, roughly
0.4 for WN4, WN6 and very close to zero for WN5. It appears
also that WN stars have more N, whereas WC stars have more C

and O at the surface. Elementary considerations suggest that
layers coming from regions of internal nucleosynthesis (CNO
for WN stars, and 3α for WC stars) are to be exposed at the
surface to explain those chemical compositions. Paczynski
(1973) suggested the peeled onion skin model that relies on
the existence of mass loss. Very presumably WC's should be
more evolved than WN's. The statistics about the frequency of
WR's among OB stars was elaborated by Smith (1973), and by
Moffat and Seggewiss (1978) for the transition WR's in parti
cular. Chiosi et al. (1978a) in the light of their results on
the evolution of massive stars with mass-loss in blue and red
phases rediscussed the problem of the theoretical interpreta
tion of WR stars.

Before proceeding further it must be emphasized that
Chiosi's et al. (1978a) scenario was aimed to suggest a plau
sible explanation of single WR's, and is not in conflict with
the mass exchange mechanism in binary systems. In their scena
rio, all single WR stars are in the core He-burning phase,
whereas the existence of different classes is interpreted in
terms of the progenitor mass and overall effect of mass loss.
As far as the progenitor star is concerned, single stars
with initial mass smaller than 20-25 $M_\odot$ would never undergo
a WR phase as a consequence of mass loss by stellar wind in
the course of their evolution. The computations in fact indi
cate that very little mass is lost on the whole, preventing
the stars from showing very low H content at the surface.
They should behave as standard main sequence and supergiant
stars but with minor changes caused by the existence of mass
loss (e.g. anomalies in the surface chemical composition,
Luck 1977a,b; 1978).

Single stars with initial mass in the range 20-25 $M_\odot$ to
40-50 $M_\odot$ would first appear as WN and later as WC during the
most advanced stages of central He-burning. This is due to
the combined effect of mass loss during the core H-burning
(radiation pressure) and He-burning (acoustic flux driven
wind, and radiation pressure). When the stationary He-burning
in the core is initiated, the models run blueward in the HR
diagram, still having a rather thin H-rich envelope at the
top of the He core. This envelope can be easily lost by the
star on a time scale shorter than the He-burning lifetime if
mass loss, presumably by radiation pressure, were to occur
at a rate compatible with the current estimate for WR stars
(10^{-5} to 10^{-4} $M_\odot$/yr). It was also suggested that single WC
stars would correspond to the fraction of the core He-burning
lifetime after the removal of the whole H-rich envelope and
before the central exhaustion stage. WN stars would occur of
course before the H-rich envelope is lost and after the models
have already moved to high effective temperature (Log $T_e \gtrsim 4.3$).
In fact, although the models were not carried until the cen-
tral He-exhaustion stage, still they went very near to the
area of classical WN and WC stars. Finally, stars of initial

mass greater than 40-50 $M_\odot$ would also undergo a WR phase du-
ring their core H-burning phase but appearing only as transi-
tion WR's, as they would die before the H-rich envelope is
completely lost. The ultimate motivation of this picture
rests on the high efficiency of mass loss during core H-burn-
ing phase in massive stars. The numerical computations of
Chiosi et al. (1978a) seem in fact to indicate that when the
mass of the H-rich envelope reduces below 40% of the total
mass no red models are possible; mass loss at low effective
temperature loses part of its importance. A relative signifi-
cant H-rich envelope is left and the time scale necessary to
remove it is longer than the core He lifetime. Later phases
are unrelevant to this purpose owing to their extremely short
lifetime in presence of the neutrino cooling. Our predictions
for the transition WR's is somewhat supported by the observa-
tional analysis of Moffat and Seggewiss (1978). In conclusion,
the transition WR's have evolved from progenitors of higher
mass than all other WR stars and moreover in view of their
distinct luminosity gap in the HR diagram very presumably
they would not evolve into other subclasses.

     A further speculation suggested by the above picture is
the ultimate fate of stars in the range of mass 20-25 $M_\odot$ to
40-50 $M_\odot$. If we ask the question of the optical appearance
of a SN produced by the explosion of stars deprived of their
H-rich envelope, their spectrum could resemble to SNI spec-
trum. At the time being there is no strong observational evi-
dence of this category of type I supernovae, and further in-
vestigation is necessary to elucidate the point.

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DISCUSSION FOLLOWING CHIOSI, NASI and BERTELLI

de Loore: How can you explain that during the acoustic flux regime mass loss the luminosity increases? I should presume that due to entropy losses the luminosity drops. I would refer to our computations for a 30 $M_\odot$ star, lowered to 17.8 $M_\odot$ owing to stellar wind, where at the red giant stage a mass loss rate of 4.10^{-3} $M_\odot yr^{-1}$ was applied. There the track goes down as it should. I think that energy losses should be taken into account.

Chiosi: I agree with you and I believe that a fully hydro-dynamical approach would be much more appropriate.

Mazurek: Type I supernovae have large expansion velocities, implying a relatively low mass (~ 1 $M_\odot$). You are making Type I supernovae out of massive (~ 50 $M_\odot$) stars. How can you justify this?

Chiosi: In my picture I was trying to suggest that a new kind of Type I supernovae might be originated by rather massive stars say between 30 to 60 $M_\odot$. This suggestion is however very speculative as we do not yet have any observational support for this. The statistics should be in any case rather poor