THE EVOLUTION OF THE COMPOSITION OF A YOUNG STAR CLUSTER EJECTA

Mercedes Mollá (CIEMAT, Madrid),
& Roberto Terlevich (INAOE, Puebla, México)

ABSTRACT

We have computed with a fine time grid the evolution of the elemental abundances of He, C, N and O ejected by young (t < 20Myr) and massive ($M = 10^6$ Msun) coeval stellar cluster with a Salpeter initial mass function (IMF) over a wide range of initial abundances.

Our computations incorporate the mass loss from massive stars (M > 30 Msun) during their wind phase including the Wolf-Rayet phase and the ejecta from the core collapse supernovae.

We find that during the Wolf-Rayet phase (t <5 Myr) the cluster ejecta composition suddenly becomes vastly over-abundant in N for all initial abundances and in He, C, and O for initial abundances higher than 1/5th Solar. The C and O abundance in the cluster ejecta can reach over 50 times the solar value with important consequences for the chemical and hydro-dynamical evolution of the surrounding ISM.

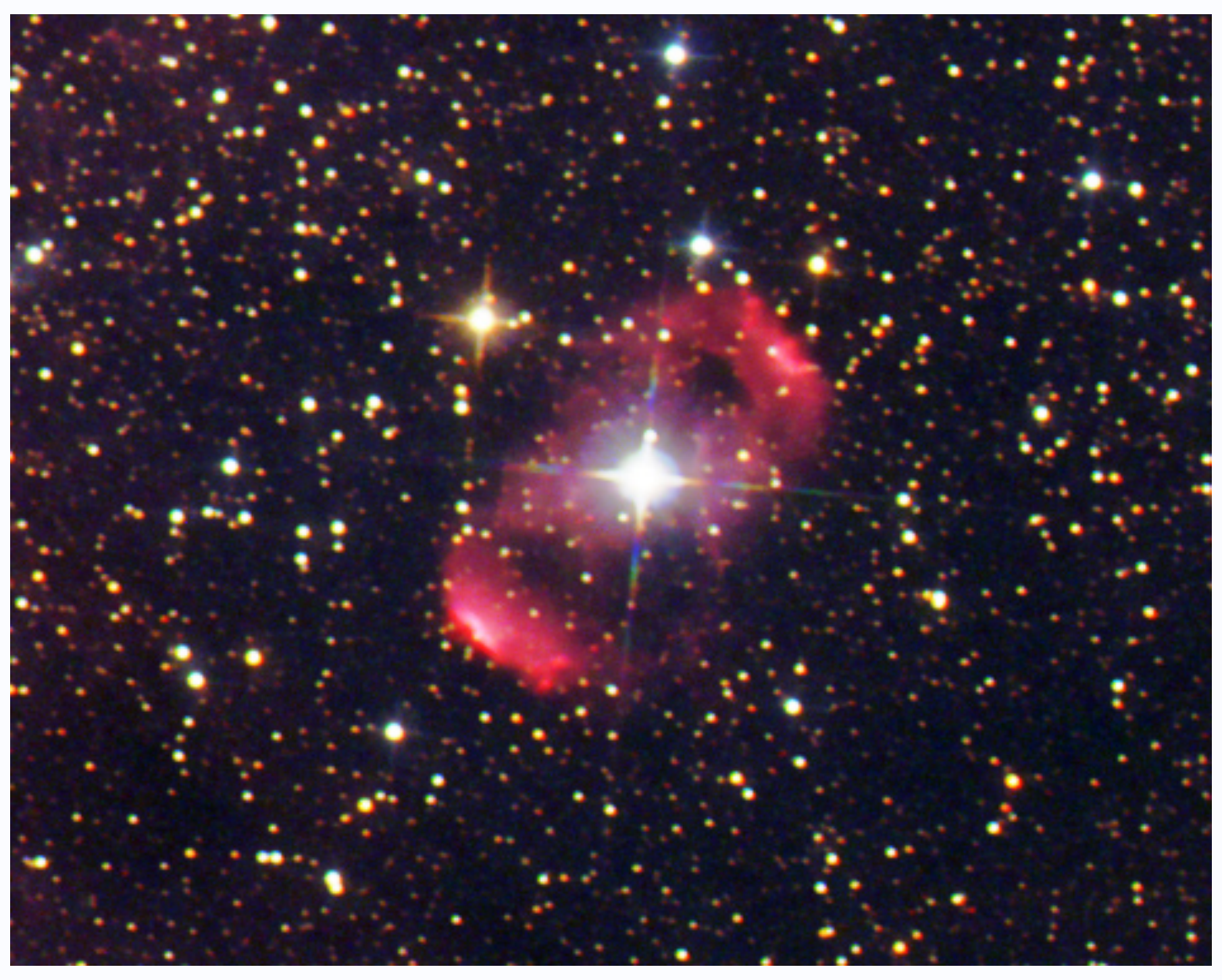


Image 1. Nebula NGC6164-65. The central star is a Wolf-Rayet star. Wolf-Rayet stars are hot (25-50,000+ degrees K), massive stars (20+ solar mass) with a high rate of mass loss. The central star is actully a triplett system. Credit: Imaged at IAS observatory, Farm Hakos, Namibia.

Image 2: Three-colour composite of the sky region of M 17, a H II region excited by a cluster of young, hot stars. The present image was obtained with the ISAAC near-infrared instrument at the 8.2-m VLT ANTU telescope at Paranal. Credit:ESO

INTRODUCTION

❖The luminous and rapidly evolving massive stars supply the UV radiation that creates the HII region and eject a large amount of mass and mechanical energy in the form of supernova ejecta and stellar winds particularly during the WR phase (see Image 1). The massive star-forming clusters can eject during their first 10 Myr of evolution about 20% of their initial mass mostly C, N and O

❖The time scale for cooling is strongly dependent on the gas cooling rate that in turn is dependent on the gas chemical composition and density.To evaluate the time evolution of a stellar cluster it is necessary to estimate the cooling function and to compute the cooling and feedback time scales.

❖In galactic chemical evolution models the elements ejected by the stellar cluster are incorporated to the ISM when the corresponding stars die. The shortest time step, defined by the mean-lifetime of the most massive star, typically around 100–120 M⊙, is around 3-5 Myr. This way important phases of the wind evolution, occurring before 3Myr or short lived like the WR phase are lost or diluted.

❖Most chemical evolution models use the total yields of elements due to supernova explosions, such as those given by Woosley & Weaver (1995) or other more recent works to calculate the total change of the elemental abundances. Other computations include the elements ejected during the wind phase of massive stars.

❖Only Portinari, Chiosi & Bressan (1998) include both the yields of core collapse supernova explosions and the stellar wind yields produced during the evolution of each star. However, these computations, as explained, were performed with time steps much longer than the lifetime of a HII region,therefore missing short lived stages like the WR phase.

❖Moreover the yields of the supernova explosion are taken from models of core collapse supernova explosions for normal main sequence massive stars without taking into account that at the time of the explosion a massive star has a structure substantially different from the one of a normal star, due to the mass lost during its evolution (Woosley, Langer & Weaver 1993,1996)

❖In this work we calculate in detail the first 20 Myr of the evolution and chemical composition of a star cluster ejecta on very short time scales, i.e. much shorter than the HII region lifetime and in particular to resolve the WR wind phase

2 THE EVOLUTION OF ABUNDANCES OF THE STELLAR CLUSTER DUE TO MASS LOSS BY STELLAR WINDS

❖To compute the evolution of a stellar cluster ejecta we have assumed that the cluster stellar mix consists of a coeval population or single stellar population (SSP) where all stars were created simul- taneously and with the same metallicity.

❖It is easy to calculate in each time step the contribution of each star, *m*, weighted by the number of stars in its mass range, given by the initial mass function Φ(*m*). For each element i, and each time *t*:

$$m_{ej,i}(t) = \int_{mlow}^{mup} \int_{\Delta t} e_i(m,t')dmdt'$$

where $ez,i(m,t') = XSi(m,t')$dm/dt

$XS\ i(m,\ t)$ is the surface abundance of each element *i* and

dm/dt(*t*) is the mass loss rate for each stellar mass *m* in every time *t*.

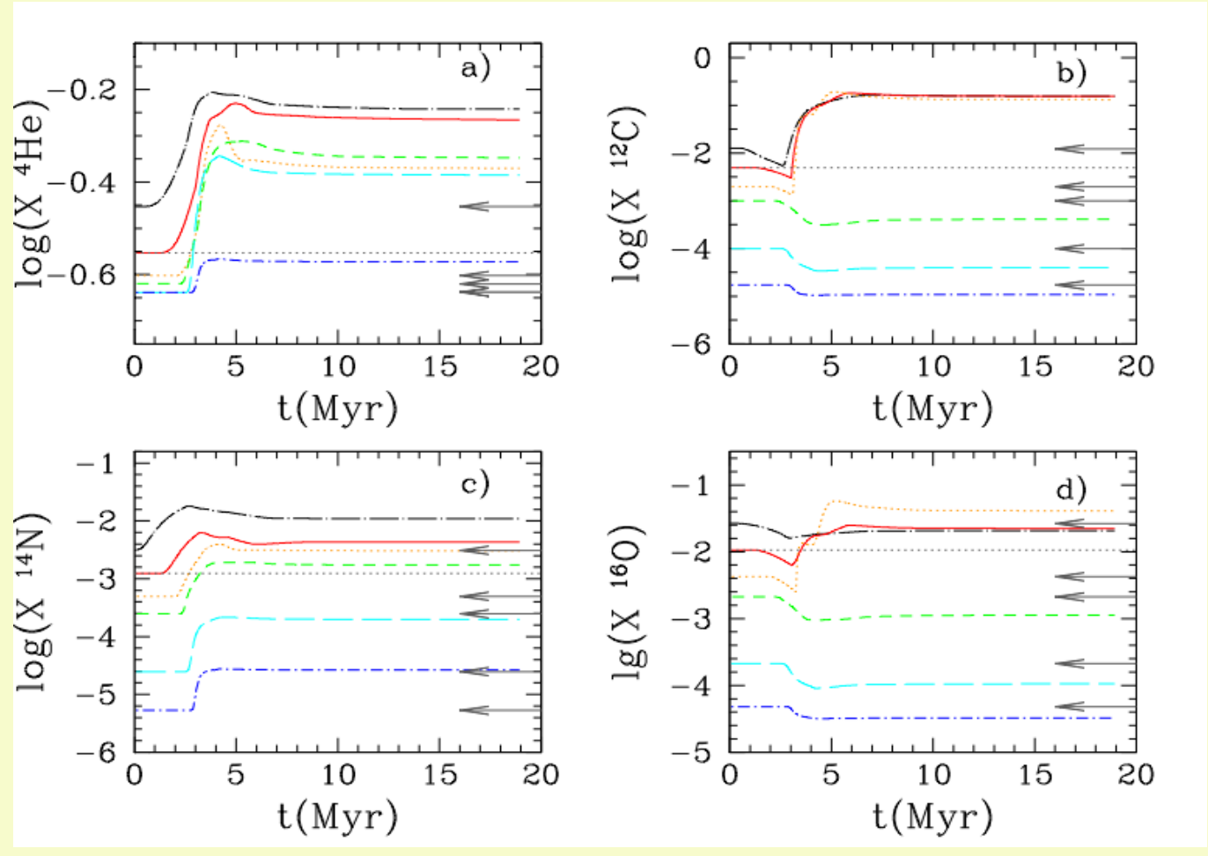


Fig 3. Evolution of abundances in mass of the accumulated masses ejected by a stellar cluster for a) He, b) C,c) N and d) O.

❖Fig. 3 a sharp increase for $Z \geq 0.008$ due to the mass loss of massive stars followed by a plateau after the peak of mass loss associated with the WR stars decline.

3. SUPERNOVA EJECTIONS

❖Stars more massive than $m \geq 12$ M⊙ end their evolution as core collapse supernovae. New elements are created and ejected in these events. Only after 3.7 Myr supernovae begin to contribute to the cluster ejected mass.

❖Due to the stellar wind the mass of a star at the pre-supernova stage is smaller than its main sequence mass. Thus, the supernova yields for a given star are not those corresponding its main sequence mass since the star which explodes is less massive.

❖To estimate the supernova yields we took as the supernova progenitor mass, the mass of each star at the end of its wind phase.

❖We use two different ways depending on the wind mass loss rate:

- ❖(i) Small mass loss rate.Stars with initial masses around 15M⊙ lose only part of their H, therefore XH> 0 at all times.
- ❖ii)High mass loss rate. Stars with $Z \geq 0.008$ and $M \geq 30$ M⊙, have high mass loss rates and arrive to the end of the wind phase without H envelope inducing important changes to the supernova explosion mechanism and ejecta

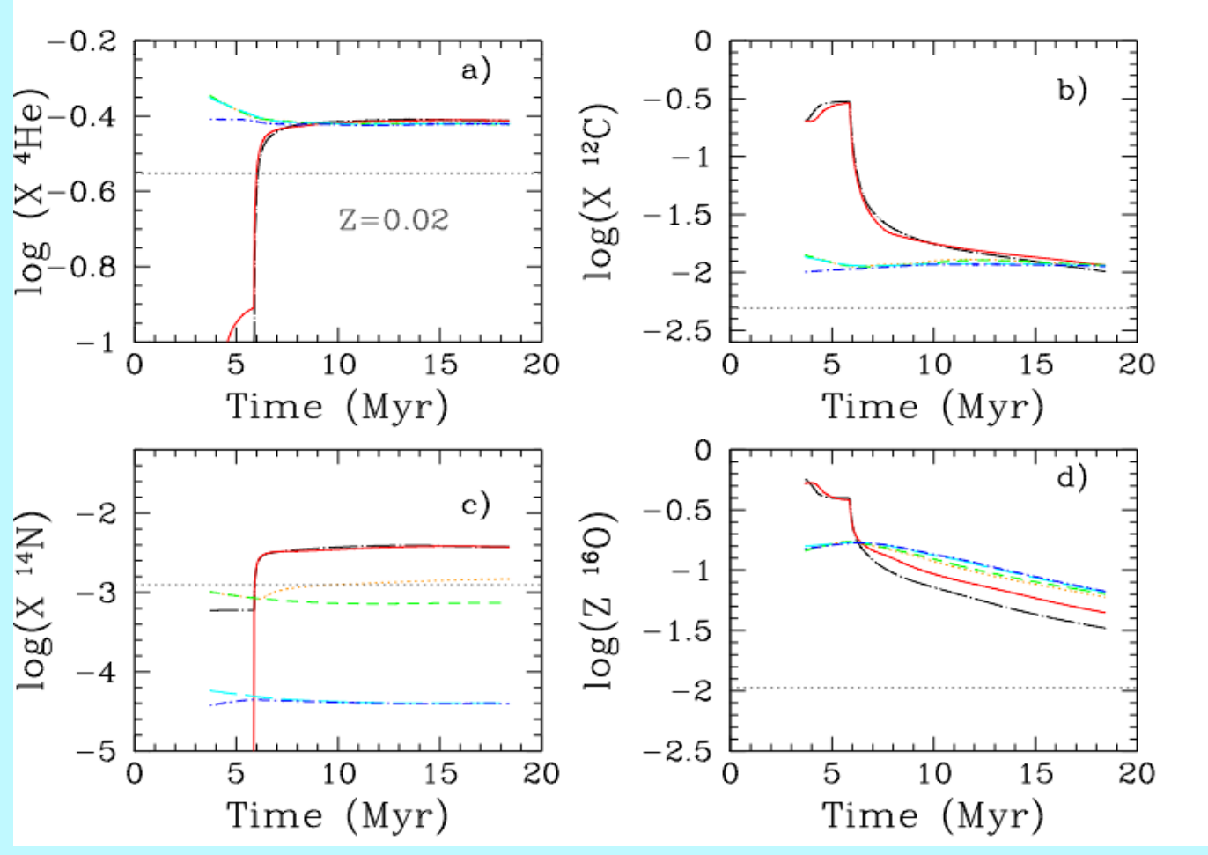


Fig.4 The evolution of the abundances of the accumulated ejected mass by a stellar cluster during the supernova phase for a) He, b) C, c) N and d) O for Z=0.02

1. THE STELLAR TRACKS

❖We use the stellar tracks from Padova group who give the evolution of massive stars and their surface elemental abundances as a function of time in form of tables.

❖Tables give the mass loss along the evolutionary stellar track for stars of 12, 15, 20, 30, 40, 60 and 100 Mo andd for 6 metallicities Z=0.0001, 0.0004, 0.004, 0.008, 0.02 & 0.05. See Fig 1

❖The surface elemental abundances are shown for Z=0.02 in Fig. 2

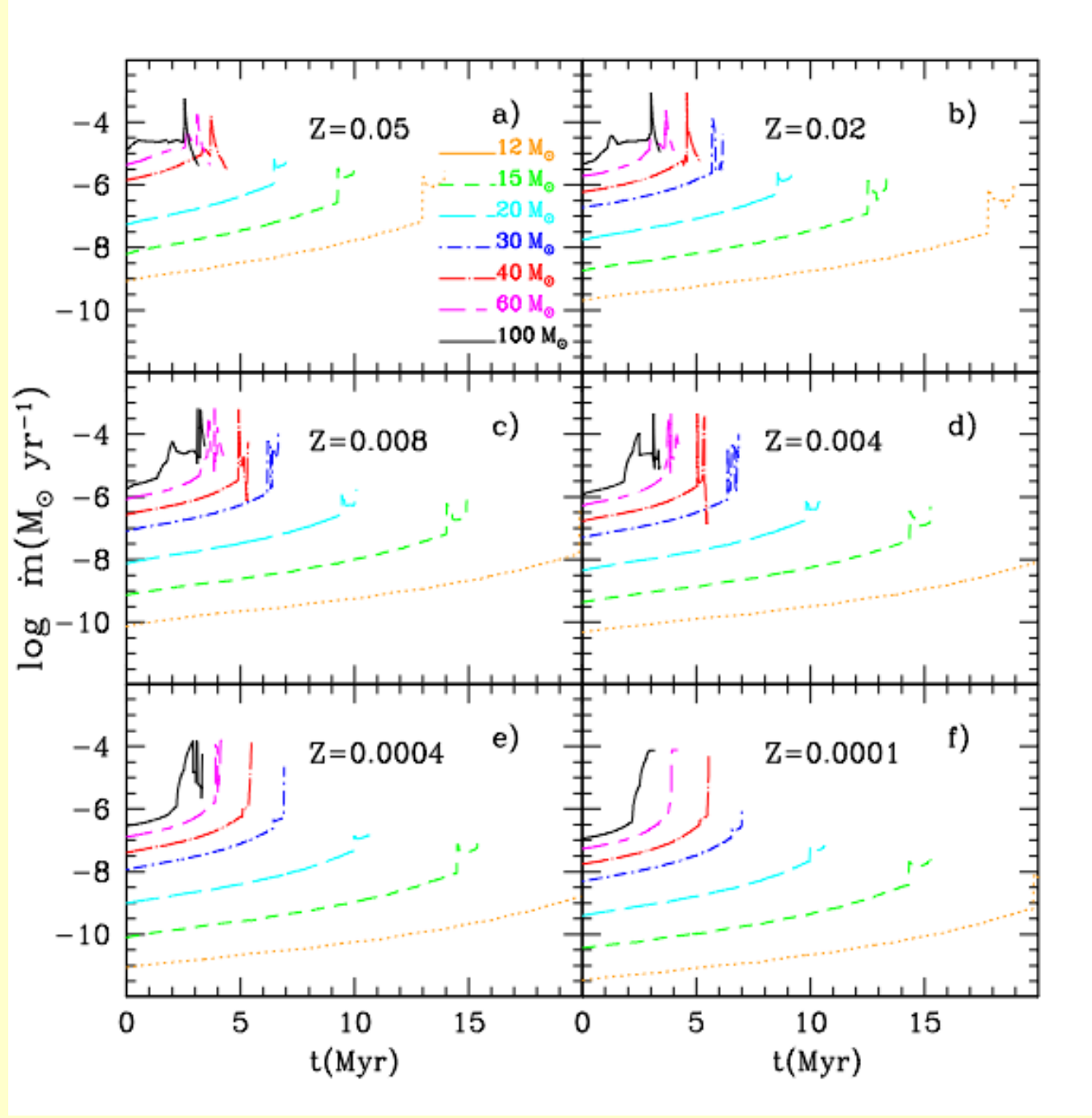


Fig.1 Mass loss for the different stellar masses and for different metallicities

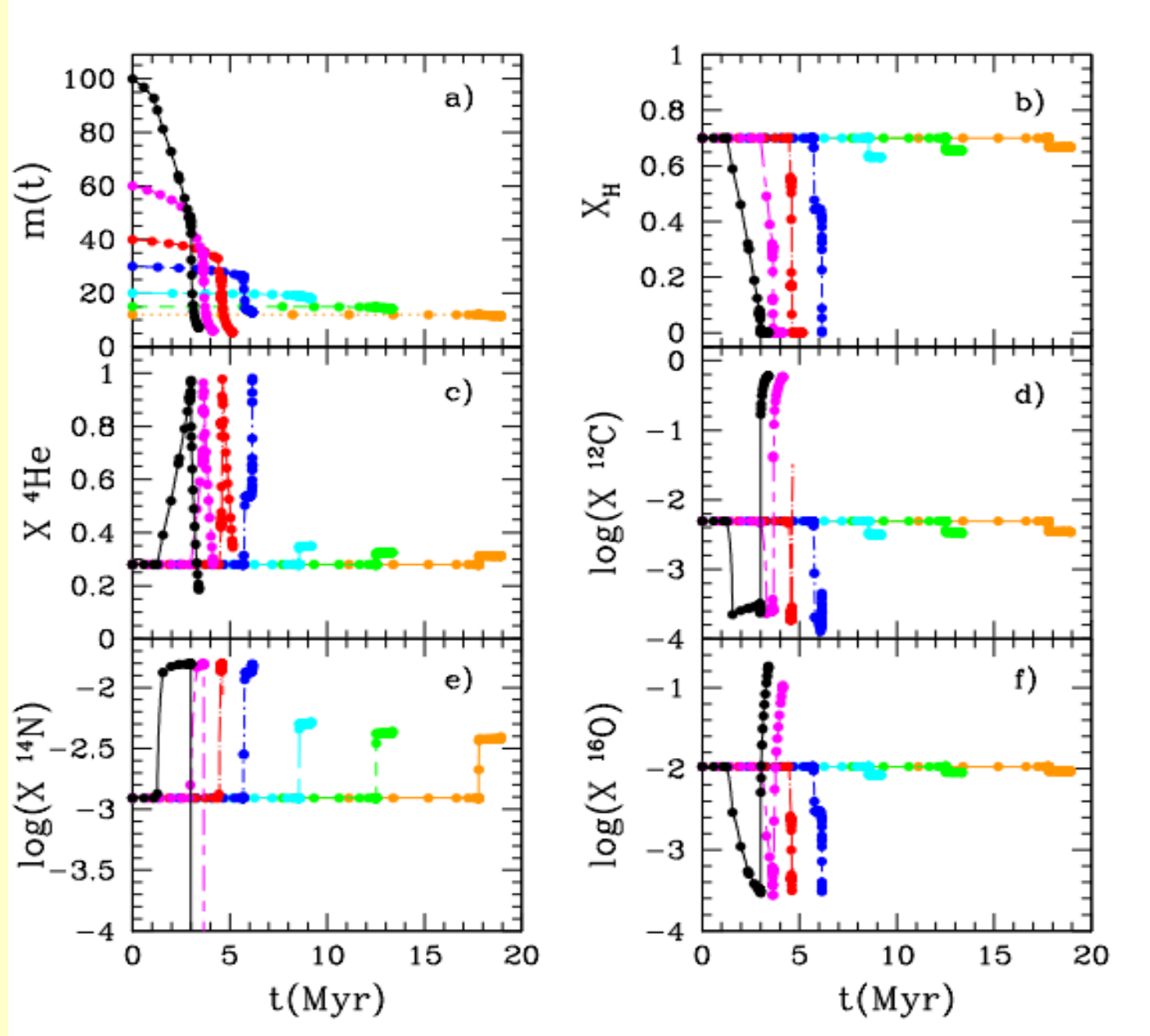


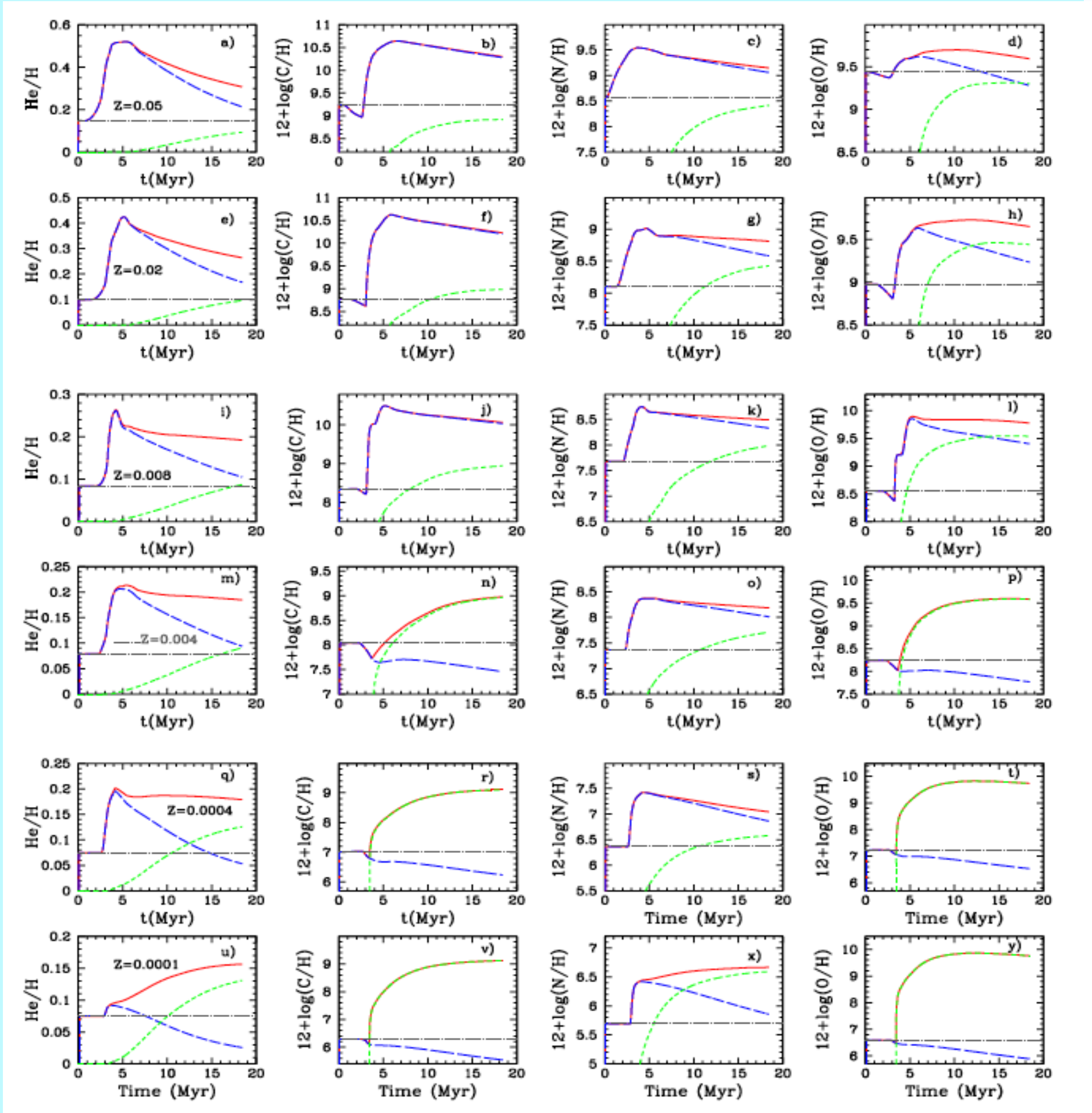
Fig.2 Time evolution of the surface elemental abundances (in mass fraction) of H, He, C, N and O for stars of different masses with Z=0.02

4. ADDING SUPERNOVA EXPLOSIONS EJECTA TO STELLAR WINDS EJECTA

❖Fig.5 shows the time evolution of abundances. We plot the contribution of winds by long dashed (blue) lines, the contribution coming from supernova with short-dashed (green) lines and the total abundances with solid (red) lines.

❖For He both contributions are more or less similar at the end of 20 Myr if Z>0.004. The abundance is a factor of two if wind ejections are considered compared to the usual calculations performed with supernova productions only. For the two lowest metallicities the ejected masses are a factor 2 or 3 smaller.

❖Stellar winds produce high abundances of C and O only for Z > 0.004. The level of 12+log(O/H) is around 9 for Z <0.004 while for higher Z it reaches almost 11, almost two orders of magnitude larger. N, however, shows higher abundances than expected for all metallicities, even for the two lowest ones.



❖C and O show very high abundances, from supernova ejecta compared with the reference values, mainly for Z < 0.004, while He and N are roughly in the expected level for its metallicity.

CONCLUSIONS

1)The composition of the ejected matter is determined mostly by supernova at low metallicities and by stellar winds at around Solar metallicities.

2)The total mass ejected by stellar winds ranges from about 1% of the initial cluster mass for the lowest metallicity model to about 6% for Solar abundance for a Salpeter IMF.

3)The total mass ejected by supernova is ~5% of the total mass of the cluster for all initial metallicities.

4)At high metallicities the mass ejected by the winds phase is around 40-60% of the total ejecta.

5)There is a large increase in the abundance of He, C, O and N after 2.5 Myr with O and C abundances being the most extreme. The O abundance increases almost two orders of magnitude between 2.5 and 4 Myr for the lowest metallicity and about 3 times for solar abundance- Between 2 and 3Myr, the C abundance increases between 10 and 30 times its initial value.

6)He and N show more moderate jumps than C and O in their abundance between 2.5 and 4 Myr. He abundance increases almost 3 times for the solar value models and about 2 times for Z=0.0004. On the other hand N shows jumps of about 5 times for all abundances. For cluster ages t < 10Myr, He and N enrichment is mainly due to the stellar winds.