The effects of population III stars on the chemical and photometrical evolution of ellipticals

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ABSTRACT

We have studied the effects of an hypothetical initial generation containing very massive stars ($M > 100 M_\odot$, pair-creation SNe) on the chemical and photometric evolution of elliptical galaxies. To this purpose, we have computed the evolution of a typical elliptical galaxy with luminous mass of the order of $10^{11} M_\odot$ and adopted chemical evolution models already tested to reproduce the main features of ellipticals. We have tested several sets of yields for very massive zero-metallicity stars: these stars should produce quite different amounts of heavy elements than lower mass stars. We found that the effects of population III stars on the chemical enrichment is negligible if only one or two generations of such stars occurred, whereas they produce quite different results from the standard models if they continuously formed for a period not shorter than 0.1 Gyr. In this case, the results are at variance with the main observational constraints of ellipticals such as the average $[\alpha/Fe]_*$ ratio in stars and the integrated colors. Therefore, we conclude that if population III stars ever existed they must have been present for a very short period of time and their effects on the following evolution of the parent galaxy must have been negligible. This effect is minimum if a more realistic model with initial infall of gas rather than the classic monolithic model is adopted. Ultimately, we conclude that there is no need to invoke a generation of very massive stars in ellipticals to explain their chemical and photometric properties.

Key words: galaxies: ellipticals, chemical abundances, formation and evolution - stars: PopIII

1 INTRODUCTION

The first stars formed out of gas with primordial chemical composition, namely without metals. Therefore, if the stellar mass distribution has not changed drastically from early times to now we would expect to find turn-off mass stars showing no metals in their atmospheres, but so far they have not been detected. However, in the past years stars with extremely low metal content down to $[Fe/H]=-5.3$ (Christlieb et al. 2002;2004) and residing in the Galactic halo have been found and it is likely that more of these stars will be observed in the future thanks to the constant improvement of the astronomical techniques and to the larger and larger stellar data samples.

From a theoretical point of view we expect very few stars with extremely low metal content since a few massive supernovae exploding at early times are sufficient to pollute the interstellar medium at levels far from zero. For example, in Chiappini et al. (2003) model for the evolution of the Milky Way it is found that to enrich the galactic halo up to $[Fe/H]=-5.0$, with the most massive stars being those of $100 M_\odot$, it takes only between 3 and $4 \cdot 10^9$ years, with the consequence of having a very small fraction (of the order of $10^{-5}$) of stars formed with metallicity below $[Fe/H]=-5.0$. Prantzos (2003) also reached similar conclusions. In the Chiappini et al. model the halo is assumed to be well mixed at any time, an assumption which seem to be reasonable given the lack of spread observed in the abundances of halo stars down to $[Fe/H]=-4.0$ (Cayrel et al. 2004: François et al. 2004). However, due to the lack of observed zero-metal stars, the idea of a primordial stellar generation made only of very massive stars, the so-called population III stars (Bond, 1981; Cayrel 1986; Carr 1987, 1994), has fascinated astronomers for many years. Recently, the WMAP experiment has observed the large-angle polarization anisotropy of the cosmic microwave background (CMB), thus constraining the total production of ionizing photons from the first stars (e.g. Cen et al. 2003 a,b; Ciardi et al. 2003), and suggesting a substantial early activity of massive star formation at redshifts $z \geq 15$. Moreover, the recent realization that the intergalactic medium seems to be enriched in metals even at high redshift, as indicated by the presence of metals in the Ly$\alpha$ forest at $z \sim 4-5$ (e.g. Songaila 2001, Schaye et al. 2003) has...
also suggested the possibility of a population III generation of stars.

From the point of view of stellar evolution, the evolution and nucleosynthesis of zero-metal massive and very massive stars has been computed since the early eighties (e.g. Carr et al. 1982; Ober et al. 1983; El-Eid et al. 1983) and has continued until recently (e.g. Woosley & Weaver, 1995; Heger & Woosley 2002; Umeda & Nomoto, 2002; Heger et al. 2003; Chieffi & Limongi 2004). Even studies of the evolution of intermediate mass (e.g. Chieffi et al. 2001; Siess et al. 2002; Iwamoto et al. 2004) and low mass stars (D’Antona 1982) with zero metallicity have appeared in the literature in the past years.

The most important question about population III stars is to decide how massive they were. Hydrodynamical simulations of the collapse and fragmentation of the primordial gas clouds suggest that the very first stars should have been indeed with masses larger than $100M_\odot$ (Bromm 1999, 2002; Abell et al. 2000;2002). Some of the stellar evolution studies mentioned before computed the evolution and nucleosynthesis of stars with main sequence masses larger than $100M_\odot$ (Ober et al. 1983; El-Eid et al. 1983; Umeda & Nomoto, 2002; Heger & Woosley, 2002). The interesting aspect of these very massive stars is that they should die as pair-creation supernovae and leave no remnants. These stars, in fact, are first characterized by the nuclearly energized pulsational instability during the phases of core H- and He-burning, which can produce substantial mass loss. Later on, a pair creation instability sets in and induces core collapse, explosive O-burning and subsequent SN explosion which disrupts completely the star. For masses larger than $200M_\odot$ it can instead occur that they implode as black holes and do not contribute to the chemical enrichment.

The effect of population III stars on the chemical evolution of galaxies has been studied a long ago (e.g. Carr et al. 1982; Chiosi & Matteucci 1982) and it was suggested that they could explain the trend of $[O/Fe]$ versus $[Fe/H]$ observed in the Milky Way stars. However, at that time, detailed calculations of the effect of type Ia SNe in explaining that trend had not yet appeared (Greggio & Renzini, 1983; Matteucci & Greggio 1986). Nowadays, we interpret the run of $[O/Fe]$ vs. $[Fe/H]$ as due to the time-delay between the production of oxygen by type II SNe and Fe by type Ia SNe. However, in spite of the better knowledge of chemical evolution that we have now relative to then, we think that it is still interesting to study the effects of population III stars on the chemical evolution, in order to impose constraints on the number and masses of these hypothetical first stars.

Recent studies dealing with the effects of population III stars on the chemical enrichment have concluded either that stars with masses between $1-40M_\odot$ must have existed together with pair creation SNe to explain the abundance pattern observed in high redshift QSOs (Venkatesan et al. 2004), or that the nucleosynthesis in pair creation SNe cannot reproduce the abundance patterns of halo stars (Umeda & Nomoto, 2002). However, in the first paper only an instantaneous starburst was considered and in the second only a simple comparison between stellar production ratios and abundances was performed.

In this paper we have explored the consequences of introducing one or more generations made either only of very massive stars ($M > 100M_\odot$) or made of all stars plus the very massive ones (0.1-260$M_\odot$) in detailed chemical and photometric evolution models for a typical elliptical galaxy. The chemical and photometric models adopted for the elliptical galaxy is that of Pipino & Matteucci (2004) which best reproduces the main properties of ellipticals. This model belongs to the category of supernova-driven wind models and assumes that in ellipticals there is an early strong burst of star formation followed by the development of a galactic wind. After the wind starts, and this occurs always at times shorter than 1 Gyr, star formation is inhibited until the present time and the galaxy evolves passively. The detailed nucleosynthesis from SNe II and Ia is taken into account. In this paper we add the nucleosynthesis from early pair creation supernovae. The paper is organized as follows: in section 2 we describe the model and the prescriptions adopted for population III stars, in section 3 the results are shown and in section 4 some conclusions are drawn.

2 THE MODEL

The chemical code adopted here is described in full detail in Pipino & Matteucci (2004, PM04 hereafter). In particular, we refer to PM04 Model II input parameters as our standard model. This model is characterized by: Salpeter (1955) IMF, Thielemann et al (1996) yields for massive stars, Nomoto et al (1997) yields for type Ia SNe and van den Hoek & Groenewegen (1997) yields for low- and intermediate-mass stars. We limit our analysis to a $10^{11}M_\odot$ galaxy, but it is easy to show that the results are more general.

The model assumes that the galaxy assembles by merging of gaseous lumps (infall) on a short timescale and suffers a strong starburst which injects into the interstellar medium (ISM) a large amount of energy which triggers galactic winds. After the development of the wind, the star formation is assumed to stop and the galaxy evolves passively with continuous mass loss.

We recall here that the assumed star formation efficiency is $\nu = 10$Gyr$^{-1}$, while the infall timescale is $\tau = 0.4$Gyr in the galactic core and $\tau = 0.01$Gyr at $1R_{eff}$, respectively. A dark matter halo ten times more massive than the luminous mass and with a ratio between the effective radius and the radius of the dark matter core $R_{eff}/R_e$ = 0.1, are adopted. These values were chosen in PM04 in order to reproduce the majority of the chemical and photometric properties of ellipticals.

The photometric code is the one of Jimenez et al. (1998) (see details in PM04).

We run several models by changing the characteristics of the population III stars, but keeping a standard Salpeter (1955) IMF, with $x=1.35$ over the whole mass range.

In particular, we considered the following cases:

Case a: It is based on PM04 Model II. In particular, the reference cases $a_{1C}$, $a_{o}$ (where c stands for core and o for outskirts, respectively) are taken from PM04, their Table 5. In the other a models, we allow for the simultaneous presence of both pair-creation SNe and and stars of all masses (down to 0.1$M_\odot$). Then we assume that after a time $\Delta t_{popIII}$, in which the gas has attained a threshold metallicity $Z_{thr} \sim 10^{-3}Z_\odot$ (Umeda & Nomoto, 2002; Bromm et al. 2001), only stars with masses $<100M_\odot$ are formed. How-
ever, it is worth noting that the results do not change if we adopt a threshold $Z_{th} = 5 \cdot 10^{-2} Z_\odot$. Values as low as $Z_{th} = 10^{-5+1} Z_\odot$, as suggested by Schneider et al. (2002) are obtained already with one single generation of very massive pop III stars, analogously to what happens in the Milky Way models.

Cases in which stars in the mass range $40 - 100 M_\odot$ end their life as black holes, without contributing to the pollution of the ISM, were run for comparative purposes (labelled as BH).

Case b: As a, but without initial infall, namely they are based on the closed-box (CB) monolithic scenario. Therefore, the model presents a star formation rate peaked at the beginning of the galactic evolution (i.e. when pop III stars are thought to form).

Case c: Here we assume a strongly bimodal star formation history: in the early stages, only very massive stars ($M > 100 M_\odot$) ending as pair creation SNe are allowed to form. After a delay $\Delta t_{poppII}$, in which the star formation is possibly halted by an early galactic wind, the stars form with a standard Salpeter IMF on a range of $0.1-100 M_\odot$. The infall and star formation timescales are the same as those of Model II of PM04. The time delay, which is either 0.01 or 0.1 Gyr, is considered here as a free parameter in order to see how its variation could alter the photochemical properties of the galaxy.

In Table 1 we present the characteristics of the models: in particular, in the first column are shown the model names, in the second column is indicated the reference model we used (II stays for Model II of PM04 and CB for closed-box), in column 3 is indicated the considered spatial range in terms of galactic effective radius and in column 4 is shown whether we have considered stars in the range $40-100 M_\odot$ to be active in enriching the ISM or to collapse into black holes.

### 2.1 Population III yields

Different sets of pair creation SNe yields were taken into account, in particular:

- From Heger & Woosley (2002) (hereafter HW02). These yields are calculated for a zero metallicity chemical composition and for stars with He-core masses in the range $64-133 M_\odot$ corresponding to main sequence masses in the range $140-260 M_\odot$. For He-core masses larger than $133 M_\odot$, these authors find that a black hole is formed and no nucleosynthesis is produced. They also find that the same situation is likely to occur in stars with main sequence masses in the range $25-140 M_\odot$ and primordial chemical composition.

- From Umeda & Nomoto (2002) (hereafter UN). These authors computed the nucleosynthesis of zero metallicity stars of main sequence masses in the range $13-30 M_\odot$ and in the range $130-300 M_\odot$. They compared the abundance ratios of halo stars with the production ratios in pair-creation SNe and concluded that they are not in agreement.

- From Ober et al. (1983) (hereafter OFE83). These authors computed the yields for zero metallicity stars with main sequence masses in the range $80-500 M_\odot$. They predicted that these objects should produce mainly oxygen and strongly underproduce nitrogen and Fe-peak nuclei. We are aware that these calculations are old and could have been superseded by the previously mentioned calculations, but we think that it can be interesting to compare their results with the new ones, especially because the OFE83 yields look quite different from the others.

- From Heger & Woosley (2002) (hereafter HW02). These yields are calculated for a zero metallicity chemical composition and for stars with masses larger than $10 M_\odot$, whereas for the low and intermediate mass stars we kept the yields of van den Hoek and Groenewegen (1997) which are computed for different metal contents, including the zero-metallicity composition. This was done for the sake of simplicity, in order to be able to compare the results with those of PM04.

In Table 2 are summarized the main properties of the models for what concerns the adopted nucleosynthesis. In particular, the model names are given in the first column as in Table 1, while the second column indicates whether a population III has been considered or not, the third column shows the adopted mass range for the pop III stars. In column 4 are indicated the sources of the adopted yields for the pop III stars, in column 5 the time during which we allow the pop III stars to form and in column 6 is indicated whether the pop III stars are able to trigger a very early galactic wind.

### 3 RESULTS AND DISCUSSION

In Table 3 and in Figures 1-6 we present the results of the above described calculations. In particular, in the second column of Table 3 is shown the predicted $< Mg/Fe >$ ratio in the dominant stellar population of the studied galaxy. This value is obtained by performing a mass weighted average, as described in PM04. In column 3 and 4 are shown the mass averaged $< Fe/H >$ and $< Mg/H >$, respectively. Then in columns 5, 6 and 7 are shown the predicted colors U-V, V-K and J-K (only for the central galactic regions), respectively.

The cases a1c and a1o represent the best model of PM04 and well fit the central values of the metallicity indices $Mg2$ and $< Fe >$ as well as the central values of the colors.

The models including the nucleosynthesis from pair creation supernovae by HW02 produce results which differ only slightly from the results of the standard case. In Figure 1 we show the predicted $[O/Fe]$ versus $[Fe/H]$ diagram (oxygen is a typical $\alpha$-element) for several models: as one can see, model a2c, with the yields by HW02, predicts exactly the same behaviour of the $[O/Fe]$ ratio as model a1c (standard case without pair-creation SNe) except for the very early phases. The case a2c with popIII pair-creation SNe and HW02 yields, in fact, starts with a quite lower $[O/Fe]$ ratio, relative to the standard case, due to the fact that pair creation SNe favor the production of Fe (at variance with the results of OFE83). This ratio stays constant while the $[Fe/H]$ decreases and then increases to reach the value of the standard case when the pair-creation supernovae disappear. This inversion in case a2c is due to the presence of infall of material of primordial chemical composition. In fact, when the first very massive stars die, the $[Fe/H]$ in the ISM jumps
### Table 1. Model definition: formation process and galactic shell considered

| Model | based on | zone | $R_{\text{eff}}$ | early w. |
|-------|----------|------|------------------|----------|
| a1c   | II       | 0-0.1 | yes              |          |
| a1o   | II       | 0.9-1 | $R_{\text{eff}}$ | yes      |
| a1BH  | II       | 0-0.1 | $R_{\text{eff}}$ | no       |
| a2c   | II       | 0-0.1 | $R_{\text{eff}}$ | yes      |
| a2o   | II       | 0.9-1 | $R_{\text{eff}}$ | yes      |
| a2BH  | II       | 0-0.1 | $R_{\text{eff}}$ | no       |
| a3c   | II       | 0-0.1 | $R_{\text{eff}}$ | yes      |
| a3o   | II       | 0.9-1 | $R_{\text{eff}}$ | yes      |
| a4    | II       | 0-0.1 | $R_{\text{eff}}$ | yes      |

**No infall**

| Model | zone | $R_{\text{eff}}$ | early w. |
|-------|------|------------------|----------|
| b1    | CB   | 0-0.1            | yes      |
| b1BH  | CB   | 0-0.1            | no       |
| b2    | CB   | 0-0.1            | yes      |
| b3    | CB   | 0-0.1            | yes      |
| b4    | CB   | 0-0.1            | yes      |

**Strongly bimodal**

| Model | zone | $R_{\text{eff}}$ | early w. |
|-------|------|------------------|----------|
| c1    | II   | 0-0.1            | yes      |
| c2    | II   | 0-0.1            | yes      |
| c3    | II   | 0-0.1            | yes      |
| c4    | II   | 0-0.1            | yes      |
| c5    | II   | 0-0.1            | yes      |
| c6    | II   | 0-0.1            | yes      |
| c7    | II   | 0-0.1            | yes      |
| c8    | II   | 0-0.1            | yes      |

### Table 2. Model definition: PopIII properties

| Model | PopIII (M_⊙) | Mass range (PopIII) | yields (PopIII) | $\Delta t_{\text{PopIII}}$ (Gyr) | early w. |
|-------|---------------|---------------------|-----------------|-----------------------------------|----------|
| a1c   | no            | -                   | -               | -                                 | no       |
| a1o   | no            | -                   | -               | -                                 | no       |
| a1BH  | no            | -                   | -               | -                                 | no       |
| a2c   | yes           | 0.1-260             | HW02            | 0.004                             | no       |
| a2o   | yes           | 0.1-260             | HW02            | 0.004                             | no       |
| a2BH  | yes           | 0.1-260             | HW02            | 0.004                             | no       |
| a3c   | yes           | 0.1-270             | UN              | 0.004                             | no       |
| a3o   | yes           | 0.1-270             | UN              | 0.004                             | no       |
| a4    | yes           | 0.1-220             | OFE83           | 0.006                             | no       |

**No infall**

| Model | PopIII (M_⊙) | Mass range (PopIII) | yields (PopIII) | $\Delta t_{\text{PopIII}}$ (Gyr) | early w. |
|-------|---------------|---------------------|-----------------|-----------------------------------|----------|
| b1    | no            | -                   | -               | -                                 | no       |
| b1BH  | no            | -                   | -               | -                                 | no       |
| b2    | yes           | 0.1-260             | HW02            | 0.004                             | no       |
| b3    | yes           | 0.1-270             | UN              | 0.004                             | no       |
| b4    | yes           | 0.1-220             | OFE83           | 0.006                             | no       |

**Strongly bimodal**

| Model | PopIII (M_⊙) | Mass range (PopIII) | yields (PopIII) | $\Delta t_{\text{PopIII}}$ (Gyr) | early w. |
|-------|---------------|---------------------|-----------------|-----------------------------------|----------|
| c1    | yes           | 140-260             | HW02            | 0.001                             | no       |
| c2    | yes           | 140-260             | HW02            | 0.010                             | no       |
| c3    | yes           | 140-260             | HW02            | 0.100                             | no       |
| c4    | yes           | 140-260             | HW02            | 0.100                             | yes      |
| c5    | yes           | 140-270             | UN              | 0.010                             | no       |
| c6    | yes           | 140-270             | UN              | 0.100                             | no       |
| c7    | yes           | 108-220             | OFE83           | 0.010                             | no       |
| c8    | yes           | 108-220             | OFE83           | 0.100                             | no       |
Table 3. Model predictions

| Model  | $<\text{Mg/Fe}>$ | $<\text{Fe/H}>$ | $<\text{Mg/H}>$ | U-V | V-K | J-K |
|--------|-----------------|-----------------|-----------------|-----|-----|-----|
| a1c    | 0.206           | 0.116           | 0.07            | 1.39| 3.10| 1.03|
| a1o    | 0.532           | -0.145          | -0.218          | 1.17| 2.75| 0.91|
| a1BH   | -0.03           | 0.06            | -0.04           | 1.17| 2.75| 0.90|
| a2c    | 0.213           | 0.08            | 0.04            | 1.38| 3.07| 1.02|
| a2o    | 0.415           | -0.09           | -0.217          | 1.42| 3.13| 1.04|
| a2BH   | -0.04           | 0.07            | 0.06            | 1.42| 3.13| 1.04|
| a3c    | 0.213           | -0.08           | -0.217          | 1.42| 3.13| 1.04|
| a3o    | 0.458           | -0.08           | 0.06            | 1.74| 3.60| 1.18|
| a4     | 1.03            | 0.07            | 0.05            | 1.74| 3.60| 1.18|

No infall

| Model  | $<\text{Mg/Fe}>$ | $<\text{Fe/H}>$ | $<\text{Mg/H}>$ | U-V | V-K | J-K |
|--------|-----------------|-----------------|-----------------|-----|-----|-----|
| b1     | 0.507           | -0.06           | 0.04            | 0.76| 2.73| 0.93|
| b1BH   | 0.300           | -0.247          | 1.02            | 2.69| 0.89| 1.23|
| b2     | 0.342           | 0.231           | 1.81            | 3.76| 1.23| 1.23|
| b3     | 0.382           | 0.299           | 1.82            | 3.76| 1.24| 1.24|
| b4     | 4.66            | -0.06           | 0.06            | 1.18| 3.00| 1.00|

Strongly bimodal

| Model  | $<\text{Mg/Fe}>$ | $<\text{Fe/H}>$ | $<\text{Mg/H}>$ | U-V | V-K | J-K |
|--------|-----------------|-----------------|-----------------|-----|-----|-----|
| c1     | 0.215           | 0.09            | 0.06            | 1.39| 3.11| 1.03|
| c2     | 0.156           | 0.10            | 0.08            | 1.43| 3.14| 1.04|
| c3     | 0.161           | 0.10            | 0.08            | 1.43| 3.13| 1.04|
| c4     | 0.122           | 0.66            | 0.77            | 2.22| 3.99| 2.12|
| c5     | 1.070           | 0.09            | 0.09            | 1.31| 2.98| 0.99|
| c6     | 2.56            | 0.01            | 1.02            | 2.18| 3.98| 1.27|

Figure 1. The $[\text{O/Fe}]$ vs. $[\text{Fe/H}]$ relations in the gas of a typical elliptical galaxy as predicted by various models. The time for the occurrence of a galactic wind is also marked on the curves. The time for model $a1BH$ is the same as for model $a1c$.

immediately at the value of $[\text{Fe/H}]=-1.0$ but soon this value decreases due to the infalling gas. Model $b2$ is the equivalent of the standard model without infall (CB). In this case, the model predicts a lower $[\text{O/Fe}]$ ratio at the beginning which increases later on, but no inversion in the $[\text{Fe/H}]$.

In figure 2 we show the same plot of $[\text{O/Fe}]$ vs. $[\text{Fe/H}]$...
Figure 3. The $[\text{O/Fe}]$ vs. $[\text{Fe/H}]$ relations in the gas of a typical elliptical galaxy as predicted by $c3$, $c6$ and $c8$ models (strongly bimodal cases with different nucleosynthesis prescriptions for pair-creation SNe). The time for the occurrence of a galactic wind is not marked on the curves since it corresponds to the same one as in models $a1c$ and $2c$.

for the models $b4$ and $b1$ (shown again for comparison). Model $b4$ differs from model $b1$ only for the nucleosynthesis in pair-creation SNe, which is from OFE83. One can immediately notice the large difference in the predictions of the two models: model $b4$ predicts a very high oxygen overabundance relative to Fe in the very early phases, due to the lack of Fe-peak elements in the OFE83 yields. In Figure 3 we show the $[\text{O/Fe}]$ vs. $[\text{Fe/H}]$ for the strongly bimodal star formation cases (only very massive stars in the early phases) lasting for 0.1 Gyr. Models $c3$ (yields HW02) and $c6$ (yields UN) show a rather constant $[\text{O/Fe}]$ ratio over the whole $[\text{Fe/H}]$ range. This is due to the fact that the very massive pop III stars, in the most recent nucleosynthesis calculations, produce an almost solar $\text{O/Fe}$ ratio and this will predominate also in the subsequent evolution. On the other hand, model $c8$ shows a very high oxygen overabundance relative to Fe, again due to the lack of Fe-peak elements in the yields of OFE83. The other $c$ models not included in the Figure, where the pop III stars form only for a very short time interval (0.01 Gyr) do not produce noticeable differences in the results relative to the standard $a1$ model.

While the abundances in Figures 1, 2 and 3 refer to the gas, in Figures 4 and 5 we show the predicted distributions of stars as functions of $[\text{Fe/H}]$ for models $a1c - a2c$, $b1-b2$, $c3- a1c$.

In models $a1c- a2c$ the predicted stellar distributions are almost indistinguishable except for the absence of stars with $[\text{Fe/H}] < -3.0$ in the case with pop III stars. The reason for this resides in the fact that the pop III phase is very short and at the same time the star formation rate is small at early stages when there is little gas. In the closed-box cases (models $b1$ and $b2$) the difference is more noticeable since at the beginning the star formation is quite high. In both models, in fact, no stars with metallicity lower than -3.0 and -2.0, respectively, are predicted (see Figure 4). The distribution of stars with metallicity, in turn, influences the calculation of the average $[<\text{Mg/H}>]$ and $[<\text{Fe/H}>]$ shown in table 3. For the $a1c$ and $a2c$ models clearly there is very little difference in these average values, whereas for $b1$ and $b2$ models the average $[<\text{Mg/Fe}>]$ varies from +0.507 to +0.32. Therefore, we conclude that the effect of pop III pair-creation SNe cannot be detected if ellipticals formed out of initial merging of primordial gas (infall cases).

The cases $a1$ and $a2$ labelled BH and $b1$ labelled BH (no chemical enrichment from stars in the range $40-100M_\odot$ in pop III and the following populations), predict in general lower $[<\text{Mg/Fe}>]$, $[<\text{Mg/H}>]$ and $[<\text{Fe/H}>]$ than the corresponding cases where chemical enrichment from those stars is taken into account (see Table 3). This effect is not negligible as shown for the Milky Way by De Donder & Vanbeveren (2003). However, if we consider this possibility only in pop III stars, then only negligible effects are produced on the results, and for this reason we did not show this case.

The cases $b2$, $b3$ and $b4$, differing for the pop III yields, indicate that the yields of HW02 and UN are similar, whereas the old yields by OFE83 produce quite different results especially in the predicted $[<\text{Mg/Fe}>]$ which rises up to 4.66 as opposed to $\sim 0.3$ in the other two cases. This is due to the fact that the yields of OFE83 do not contain Fe-peak elements for pair-creation SNe whereas the other yields do. Clearly this case should be discarded because it is at odd with observations which indicate a $[<\text{Mg/Fe}>] \sim 0.2-0.3$ (e.g. Thomas et al. 2002; PM04) in ellipticals.

The strongly bimodal cases ($c3$ and $c8$), where the first stellar generations are made only of pair-creation SNe, show that, if the phase during which only very massive stars form, is quite short ($< 10^7$ years), nothing changes relative to the standard case. If instead, the duration of the massive stars...
Figure 5. The same as figure 4 but for models $a1c$, $a2c$, $c3$ and $c8$. The difference between the case with very massive primordial stars ($a2c$) and the standard one ($a1c$, no very massive stars) is negligible. On the other hand, the difference between case $c3$ (only very massive pop III stars, nucleosynthesis from HW02) and $a1c$ is quite noticeable, due to the fact that pop III stars produce immediately a huge metal enrichment. Also model $c8$ (only very massive pop III stars, nucleosynthesis from OFE83) produces a very different distribution relative to $a1c$.

Figure 6. Predicted distribution of stars as a function of the $[\text{Mg}/\text{Fe}]$ ratio for models $a1c$, $a2c$, $c3$ and $c8$. As one can see, model $c8$ can clearly be discarded since it predicts that the majority of stars should have $[\text{Mg}/\text{Fe}] > 1$, at variance with observational data. Model $c3$ shows a very narrow distribution, implying that most of the stars should have the same $[\text{Mg}/\text{Fe}]$, and this is also unrealistic.

phase is as long as 0.1 Gyr, then we obtain a too high metallicity for the next stellar generations (see $[<\text{Mg}/\text{H}>]$ and $[<\text{Fe}/\text{H}>]$ in model $c3$), with the consequence of obtaining too high metallicity indices and too red integrated colors. We tried to adjust the star formation and infall parameters but could not find any acceptable solution. Therefore, such a case should be discarded. The failure of bimodal star formation in elliptical galaxies had already been discussed by Gibson (1996). In particular, he showed that this assumption leads to a metallicity -luminosity relation at variance with observations. It is worth noting that in the case $c4$ we adopted a blast wave energy for pair-creation SNe of $5 \cdot 10^{52}$ erg per SN, whereas in all the other cases we assumed the canonical value of $10^{51}$ erg. In this case a very early ($t \sim 2 \cdot 10^6$ years) galactic wind develops due to the energy injected by pair-creation SNe, and it does not destroy...
the galaxy provided that only a small fraction of gas is lost, then star formation starts again with a normal IMF when the gas has cooled down (at ~ 0.1 Gyr). After this point, the evolution is the same as in the standard case with galactic winds produced by normal type II and Ia SNe. Clearly, this is a rather arbitrary situation since there is the possibility of destroying the whole object but we made these assumptions only for the sake of testing the chemical effects of a generation of very massive stars. Always in case $c_4$, from the point of view of the enrichment of the intracluster medium (ICM), it is worth noting that the pop III chemical composition does not dominate over the ejecta of the late galactic winds produced by normal type II and Ia SNe, and this is because the galaxy can survive, in spite of the energy injected by the pop III stars, only if it looses a small fraction of gas during the very early wind. Anyway, also in case $c_4$ the predicted metallicities are too high and therefore it should be discarded.

Finally, in Figure 6 we present the stellar distributions as functions of the $\text{[Mg/Fe]}$ ratio for models $a1c$, $a2c$, $c3$ and $c8$. As one can see, model $c8$ can clearly be discarded since it predicts that the majority of stars should have $\langle \text{[Mg/Fe]} \rangle >_1$, at variance with observational data. Model $c3$ shows a very narrow distribution, implying that most of the stars should have the same $\langle \text{[Mg/Fe]} \rangle$, and this is also unrealistic. Model $a2c$, as expected has a stellar distribution as a function of $\text{[Mg/Fe]}$ more similar to that of model $a1c$, although it shows a higher peak and is truncated at the highest values of $\text{[Mg/Fe]}$, at variance with the $a1c$ case. Therefore, in general, models with pop III stars seem to worsen the agreement with observations with exception of the predicted gradient of $\langle \text{[Mg/Fe]} \rangle$ in ellipticals. An interesting fact is that model $a2$ predicts a shallower $\langle \text{[Mg/Fe]} \rangle$ radial gradient with respect to the PM04 standard case, more in line with recent observations claiming no variation of $\langle \text{[Mg/Fe]} \rangle$ with radius (Mehlert et al. 2003). In fact, in the galactic outskirts, where the star formation is limited to a shorter period and it is less intense than in the center, the effect of the pop III stars is more evident than in the center. This fact contributes to lower the predicted $\langle \text{[Mg/Fe]} \rangle$ in the outer regions, since the pop III yields predict a lower Mg/Fe ratio relative to the yields of normal massive stars. As a consequence, the $\langle \text{[Mg/Fe]} \rangle$ gradient is shallower.

4 CONCLUSIONS

In this paper we have explored the effects of one or more early stellar generations of very massive stars (population III stars) on the chemical and photometric evolution of a typical elliptical galaxy of luminous mass $M_{\text{lim}} = 10^{11} M_\odot$ and a dark matter halo ten times heavier. To do that we have adopted models already tested on elliptical galaxies, which reproduce the main properties of ellipticals (PM04). The adopted IMF has been the Salpeter (1955) one, with $x=1.35$ over the whole mass range.

We have included in the chemical evolution models different nucleosynthesis results for very massive stars ($M > 100 M_\odot$), taken both from recent and old literature.

Our results can be summarized as follows:

- Only one or two first stellar generations containing normal stars plus very massive stars included in the best model of PM04 (the galaxy forms by means of initial gas accretion), produce negligible effects on the subsequent chemical and photometric evolution, when either the yields for pair-creation SNe of HW02 or those of UN are adopted. Therefore, these models are acceptable.
- Population III stars (one or two stellar generations with nucleosynthesis either from UN or HW02) in classic monolithic models for ellipticals (closed-box) produce larger, although still acceptable, $\langle \text{[Mg/Fe]} \rangle$ ratios in the dominant stellar population relative to the standard case without population III pair-creation SNe. However, the predicted integrated colors are too red. As a consequence these models should be rejected.
- Models containing nucleosynthesis from Ober et al. (1983) for pair creation SNe, with one or two pop III stellar generations, produce quite different results relative to the other studied cases. In particular, in the framework of a monolithic closed-box model they produce a too high $\langle \text{[Mg/Fe]} \rangle$, completely at odd with what is observed ($\langle \text{[Mg/Fe]} \rangle = 0.2 - 0.3$, Thomas et al. 2002).
- Models where the first stellar generations are made only of very massive stars followed by normal stellar generations generally produce lower $\langle \text{[Mg/Fe]} \rangle$ ratios relative to the previous cases. However, they all produce too high metallicities and too red integrated colors for ellipticals, therefore they should be ruled out.
- It is worth noting that all these conclusions relative to abundance ratios would not change if the pop III stars were pre-galactic. The only difference would be found in the absolute abundances which would probably be more diluted.
- We computed the metallicity distribution of stars at the present time for all the studied cases with pop III stars. We found that in most of the models the fraction of stars with metallicity lower than [Fe/H] = -2.5 is negligible. This fact can create problems with the observed metallicity-luminosity relation (see Gibson 1996). The lack of metal poor stars is due to the very fast chemical enrichment produced by the pop III pair-creation SNe. In particular, if we assume a threshold global metal content, for the formation of very massive stars, of $Z_{90} = 10^{-5}$, $Z_\odot$, as recently suggested by Schneider et al. (2002), then the expected number of pair-creation SNe able to produce such a metallicity, in the framework of the infall model, is only between 10 and 15.
- In summary, we conclude that if the population III stars formed for a very short time, their signature on the stellar and gaseous abundances are negligible and we cannot assess their existence nor disproved it. If, on the other hand, they formed for a timescale not shorter than 0.1 Gyr then their effects are visible but produce results at variance with the main observational properties of ellipticals.
- Therefore, from the chemical and photometric point of view there is no need to invoke the existence of population III stars in ellipticals.

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