# Chemical evolution of Elliptical Galaxies and the ICM

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**Abstract.** We present a new model for the chemical evolution of elliptical galaxies taking into account SN feedback, detailed nucleosynthesis and galactic winds. We discuss the effect of galactic winds on the chemical enrichment of the ICM and compute the energy per particle injected by the galaxies into the ICM.

## 1.  The chemical evolution model for Ellipticals

We present the results obtained with a new chemical evolution model for ellipticals, based on the multi-zone model by Martinelli et al. (1998), with improved SN feedback and different prescriptions for the stellar nucleosynthesis (see Pipino et al. 2002). This model can be applied to infer the age for a single galaxy (as MS1512-cB58, see Matteucci & Pipino 2002), to test different scenarios for galaxy formation (i.e. monolithic versus hierarchical) and to predict the evolution of the chemical abundances and the energy per particle released by elliptical galaxies through galactic winds into the ICM.

### 1.1. Galactic models

We adopt two different recipes for SNIa and SNII, respectively. For SNII we assume that the evolution of the energy in the 'snowplow' phase is regulated by Cioffi, McKee & Bertschinger (1988) cooling time (for a detailed discussion see Pipino et al. 2002). This cooling time takes into account the effect of metallicity, and therefore can model in a self-consistent way the evolution of a SNR in the ISM.

On the other hand, following Recchi et al. (2001), we assume that SNIa, which explode in a medium already heated by SNII, contribute with the total amount of their energy budget, without radiative losses. In this way we obtain a total (i.e. SNIa+II) mean efficiency of energy release by SN to the ISM of $\sim 20\%$ for our best model, and derive a maximum possible efficiency (in order to have realistic models) of about $\sim 35\%$ .

We study the effects of two different sets of stellar yields on the enrichment of the ICM: **a)** For low and intermediate mass stars (0.8 $\leq$

$M/M_\odot \leq 8$) the yields by Renzini and Voli (1981). For massive stars, type II SNe ($M > 10 M_\odot$) the yields by Woosley and Weaver (1995), their case B. **b)** For low and intermediate mass stars the yields by van den Hoek & Groenewegen (1997). For massive stars, type II SNe, the yields by Thielemann et al. (1996) In both cases we use the yields by Nomoto et al. (1997) for SNIa.

Here we present the results obtained with our best model: a multizone model with Salpeter IMF, and the choice **a)** for stellar yields. The adopted cosmology is $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $H_o = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and the galaxies form at $z_f = 8$. In order to check our results we compared our prediction for the Fe enrichment of the ICM, with predictions from models with different prescriptions (see Pipino et al. 2002). Our models assume increasing efficiency of SF with galactic mass which makes larger galaxies undergo galactic wind before the smaller ones. This implies shorter star-formation timescales for more massive galaxies and allows us to reproduce the increasing trend of [Mg/Fe] with galactic mass (Matteucci 1994).

## 1.2. The age of the galaxy MS1512-cB58

We can constrain the age of the Lyman break galaxy MS1512-cB58 (showing that its chemical properties are consistent with those of an elliptical galaxy or a bulge in the early phases of its life, Matteucci & Pipino 2002). In particular, we find that this age should be $\sim 30 Myr$ by comparing our model predictions on the chemical abundances with the observations of Pettini et al. (2002). In the first figure we show the prediction for [X/Fe] vs. time (left panel), assuming that roughly half of the iron is hidden in dust grains, compared to the observations (showed as horizontal lines) with their errors. The right panel allows us to make a stronger conclusion on the age, because neither O nor N are dust depleted.

## 2. Evolution of abundances and energy in the ICM

To compute the total masses of the chemical elements, gas and total thermal energy ejected into the ICM by the cluster galaxies we integrate the contributions from the single galaxies over the cluster K-band luminosity function at each given cosmic time for clusters of different mass (temperature). For the equations and related details we direct the reader to Pipino et al. (2002).

In figure 2 we show the Fe abundance in the ICM predicted by our models compared to the observed one by White (2000) as functions of
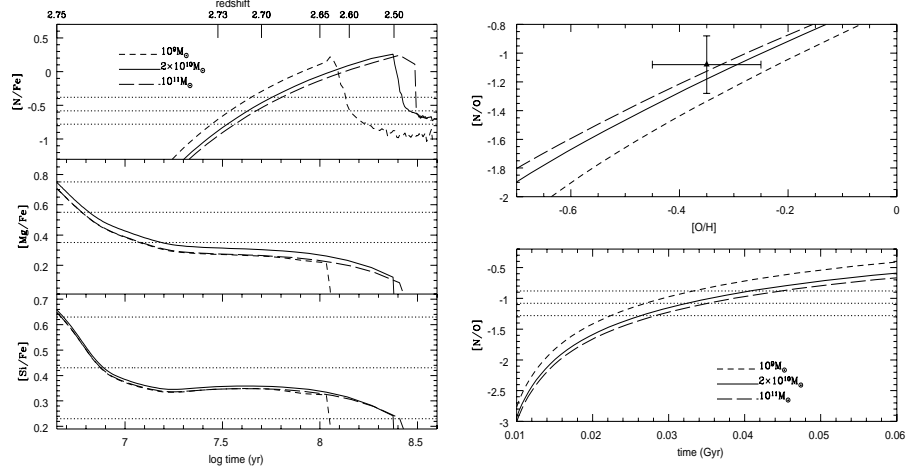
*Figure 1.* Evolution of abundances and abundance ratios in the ISM for ellipticals of different initial mass. The observed values for MS1512-cB58 (Pettini et al. 2002) are indicated (see text for details).
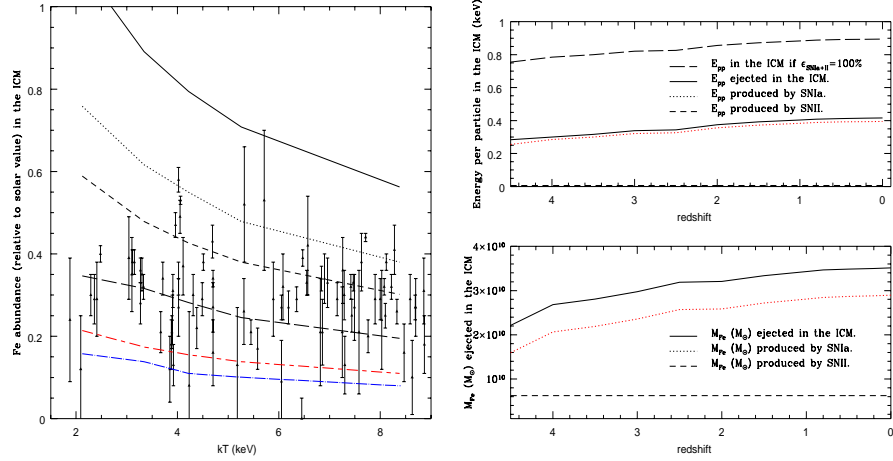


*Figure 2.* *Left:* Model predictions for the Fe abundance as a function of the temperature of the ICM compared to the data by White (2000). *Right:* predicted evolution in time of the Fe mass and the energy ejected by ellipticals into the ICM.

cluster temperature (left panel). **Our best model (with Salpeter IMF and evolution of Spirals) is shown by the long dashed line.** We have also computed the amount of metals which remains locked up inside stars. We found that the Fe in the ICM should be 5 times more than the Fe in stars, whereas O and the global metal content should be roughly the same inside stars and in the ICM.

The best model can also reproduce the observed $[\alpha/\text{Fe}]$ ratios in the ICM. In particular, there is good agreement between the predicted ($\sim$ solar) and observed ($\sim 0.1 \pm 0.1$dex) [Si/Fe] ratios, whereas the predicted [O/Fe] ratios are lower ($\sim -0.3$dex) than the solar value, as indicated by some observations (e.g. Ishimaru & Arimoto 1997). However, the O measurements in the ICM are still very sparse and uncertain and more data are required to assess this point (but see Gastaldello & Molendi 2002).

Models with the choice **b)** for the stellar yields from massive stars predict the same amount of Fe and energy in the ICM, whereas the differences in the predictions for $[\alpha/\text{Fe}]$ ratios are less than $\sim 0.2$dex.

On the right-hand side of figure 2 we show the predicted evolution of the energy per particle in the ICM, $E_{pp}$ (upper panel) and the iron mass in the ICM (lower panel) as a function of redshift by "the best model". Little evolution is found both for the abundances and for the heating energy from z=0 up to z=1, in agreement with observations (Matsumoto et al. 2000).

## 3. Conclusions

While type II SNe dominate the chemical evolution of the ellipticals (creating $\alpha$ enhancement) , type Ia SNe play a fundamental role in providing energy ($\sim 80 - 95\%$) and Fe ($\sim 45 - 80\%$) into the ICM.

Comparing masses and energy ejected by galaxies formed at $z = 8$ with those from galaxies formed at $z \sim 3$ leads to the conclusion that the bulk of the ejection has to take place at $3 < z < 5$.

The best model, which reproduces the Fe abundances in the ICM, can provide 0.20-0.35 keV of energy per ICM particle, depending on the cluster richness.

## References

Arimoto, N., Yoshii, T. 1987, A&A, 173, 23
Cioffi, D.F. et al. 1988, ApJ, 334, 252
Gastaldello, F., Molendi, S. 2002, ApJ, 572, 160
Ishimaru, Y., Arimoto, N., 1997, PASJ, 49, 1
Martinelli, A. et al. 1998, 2000, A&A, 354, 387
Matsumoto, H. et al. 2000, PASJ, 52, 153
Matteucci, F. 1994, A&A, 288, 57
Matteucci, F., Pipino, A. 2002, Apj, 596, L6
Nomoto, K. et al. 1997, Nucl. Phys. A, 621, 467
Pettini, M. et al. 2002, ApJ, 569, 742
Pipino, A. et al. 2002, NewA, 7, 227
Recchi, S. et al. 2001, MNRAS, 322, 800
Renzini, A. 1997, ApJ, 488, 35
Renzini, A., Voli, M. 1981, A&A, 94, 175
Thielemann et al. 1996, ApJ, 460, 480
van den Hoek, L.B., Groenewegen, M.A.T. 1997, A&AS, 123, 305
White, D.A. 2000, MNRAS, 312, 663
Woosley, S.E., Weaver, T.A. 1995, ApJS, 101, 181