

**\*\*TITLE\*\***

*ASP Conference Series, Vol. \*\*VOLUME\*\*, \*\*PUBLICATION YEAR\*\**

**\*\*EDITORS\*\***

## A chemical evolution model for galaxy clusters

L. Portinari

*Theoretical Astrophysics Center, Juliane Maries Vej 30,  
DK-2100 Copenhagen Ø, Denmark*

A. Moretti and C. Chiosi

*Dipartimento di Astronomia, Vicolo dell'Osservatorio 2,  
I-35122 Padova, Italy*

**Abstract.** We develop a toy-model for the chemical evolution of the intra-cluster medium, polluted by the galactic winds from elliptical galaxies. The model follows the “galaxy formation history” of cluster galaxies, constrained by the observed luminosity function.

### 1. Introduction

To account for the large amount of metals observed in the intra-cluster medium (ICM), some non-standard stellar Initial Mass Function (IMF) has been often invoked for cluster ellipticals, such as a more top-heavy IMF than the Salpeter one (Matteucci & Gibson 1995; Gibson & Matteucci 1997ab; Loewenstein & Mushotzky 1996), or a bimodal IMF with an early generation of massive stars (Arnaud et al. 1992; Elbaz, Arnaud & Vangioni-Flam 1995); see also the review by Matteucci (this conference). A non-standard IMF in ellipticals has been suggested also on the base of other arguments: a top-heavy IMF best reproduces their photometric properties (Arimoto & Yoshii 1987), and systematic variations of the IMF in ellipticals of increasing mass might explain the observed trend  $M/L \propto L$  (Larson 1986, Renzini & Ciotti 1993, Zepf & Silk 1996).

Chiosi et al. (1998) developed chemo-spectrophotometric models for elliptical galaxies with galactic winds, adopting the variable IMF by Padoan, Nordlund & Jones (1997, hereinafter PNJ) which is naturally skewed toward more massive stars in the early galactic phases, in more massive galaxies and for higher redshifts of formation (see also Chiosi 2000). These galactic models were successful at reproducing a number of spectro-photometric features of observed ellipticals; now, an immediate question is: what do these galactic models predict for the pollution of the ICM through galactic winds (GWs)?

### 2. Galactic wind ejecta: PNJ vs. Salpeter IMF

To address this issue, Chiosi (2000) calculated multi-zone chemical models of elliptical galaxies with the PNJ IMF, together with models with the standard Salpeter IMF for the sake of comparison. Before discussing the resulting global chemical evolution of the ICM, let's inspect the different GW ejecta of the model ellipticals when the two IMFs are adopted in turn.

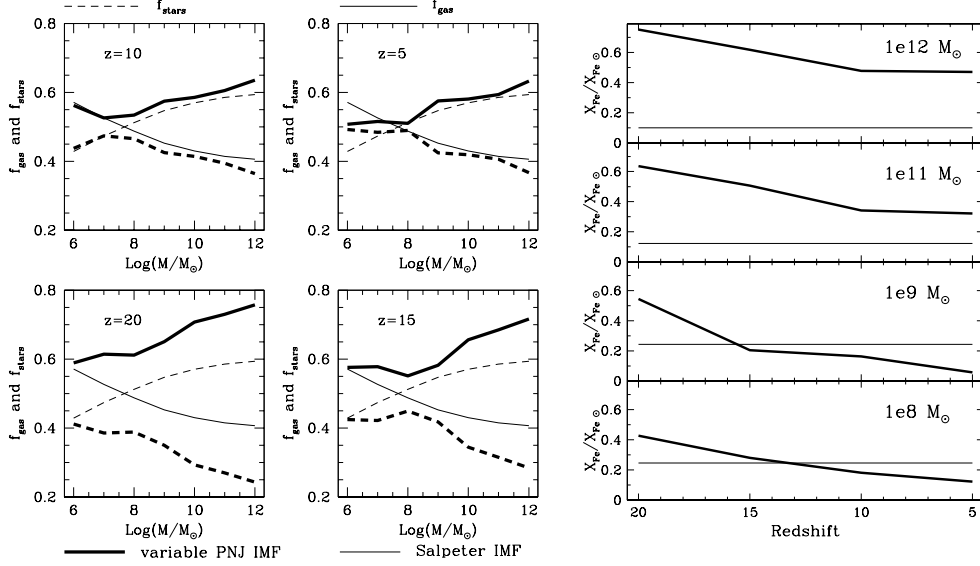


Figure 1. Comparison between galactic models with the variable PNJ IMF (*thick lines*) and models with the Salpeter IMF (*thin lines*). *Left panels*: mass fraction of ejected gas (*solid lines*) and complementary fraction locked into stars (*dashed lines*) as a function of the initial mass of the galaxy, for four different redshifts of formation as indicated. *Rightmost panel*: metallicity of the gas ejected as GW by galaxies of given initial baryonic mass, indicated in the plots, and as a function of their redshift of formation.

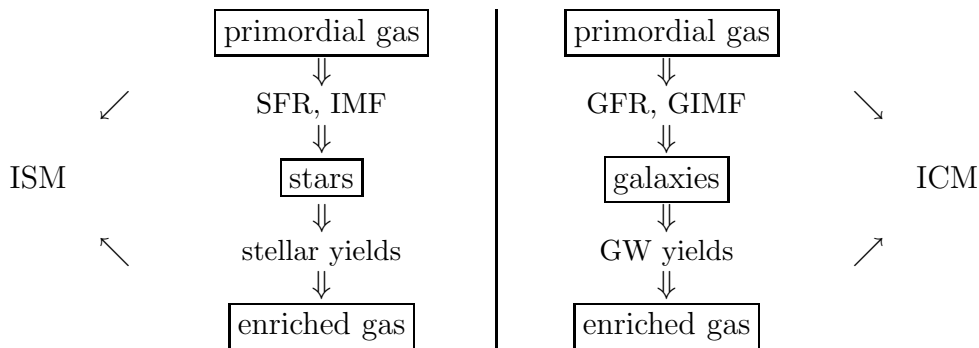
In Fig. 1 (left panels) we compare the mass fraction of gas ejected in the GW, and the complementary mass fraction locked into stars, for galactic models with the variable PNJ IMF and for models with the Salpeter IMF (thick and thin lines, respectively). Mass fractions refer to the total initial baryonic mass of the galaxy. The amount of ejected gas is larger in the case of the PNJ IMF, since in the early galactic phases this IMF is skewed toward more massive stars and less mass remains locked into long-lived, low-mass stars. The difference with the Salpeter case gets sharper for larger galactic masses, and for higher redshifts of formation. Models with the Salpeter IMF evidently bear no dependence on the redshift of formation.

The rightmost panel in Fig. 1 shows the iron abundances in the gas ejected as GW, again comparing the Salpeter IMF and the PNJ IMF case. In most cases, the galactic ejecta in the PNJ models are more metal-rich than in the Salpeter case, up to a factor of 5 or more for the more massive galaxies, and for high redshifts of formation. In the PNJ models, in fact, more gas in the galaxy gets recycled through massive stars, effective metal contributors, while less gas gets locked into low-mass stars.

From the trends described above, we expect galactic models with the PNJ IMF to predict, for the ICM, a more efficient metal pollution and a higher fraction of the gas originating from GWs, with respect to “standard” models. The first results in this respect are discussed in Chiosi (2000).

### 3. The chemical evolution of the ICM: a toy model

Since the GW ejecta of ellipticals modelled with the PNJ IMF are sensitive to the detailed redshift of formation of the individual galaxies, to predict the chemical enrichment of the ICM we need to model the history of galaxy formation in the cluster. To this aim, we developed a global, self-consistent chemical model for the cluster, which can follow the simultaneous evolution of all its components: the galaxies, the primordial gas, and the gas processed and re-ejected via GWs (Moretti et al. 2001). Our chemical model for clusters is developed in analogy with the usual chemical models for galaxies, as illustrated in the scheme below.



As the interstellar medium (ISM) is polluted by stars, the ICM is polluted by galaxies. The primordial gas in the ICM gets consumed in time by some prescribed Galactic Formation Rate (GFR); at each time galaxies form distributed in mass according to a Galactic Initial Mass Function (GIMF), derived from the Press-Schechter mass function suited to that redshift. Through GWs, galaxies reconstitute chemically enriched gas, which mixes with the overall ICM; the latter consists of the primordial gas not yet consumed by galaxy formation (if any) and of the gas re-ejected by galaxies up to the present age.

Model equations parallel those of galactic chemical models, with the substitutions  $\text{SFR} \rightarrow \text{GFR}$ ,  $\text{IMF} \rightarrow \text{Press-Schechter GIMF}$ ,  $\text{stellar yields} \rightarrow \text{GW yields}$ . Model parameters are calibrated so that the resulting galaxy formation history matches the observed present-day luminosity function (LF) at the end of the simulation. For all details, see Moretti et al. (2001).

### 4. The “best case” models

In Fig. 2 we show our case of “best match” with the observed LF in the B-band (Trentham 1998, top panels). The left panels refer to the case when galactic models with the PNJ IMF are adopted; the right panels display results for the same cluster parameters (i.e. same galaxy formation history), but adopting ellipticals with the Salpeter IMF. The Salpeter case predicts somewhat more galaxies in the high-luminosity bins, due to the fact that for massive galaxies a larger mass fraction remains locked into stars in the Salpeter case than with the PNJ IMF (cf. Fig. 1). Anyways, the LF is still in agreement with the observed one within errors.

Although the predicted LF is virtually the same in the two models, strong differences are found in the predicted gas and metallicity content in the ICM.

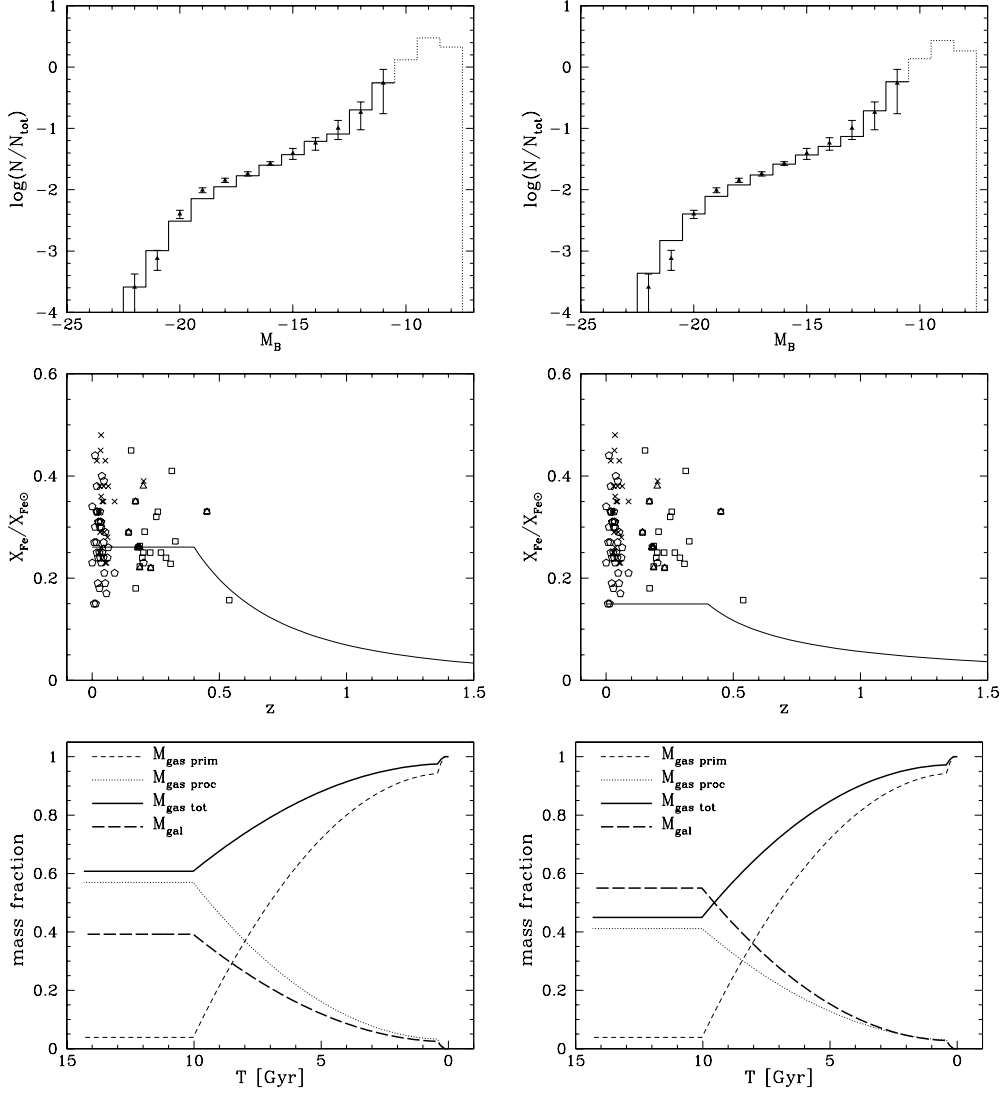


Figure 2. Results of our “best case” cluster model. *Left panels:* results for galactic models with the PNJ IMF; *right panels:* results for galactic models with the Salpeter IMF.

*Top panels:* B-band luminosity function of cluster galaxies versus the observational data (by Trentham 1998). *Mid panels:* predicted metallicity evolution of the ICM versus the observational data (by Matsuoto et al. 2000, Fukazawa et al. 1998, Mushotzky & Loewenstein 1997). *Bottom panels:* Time evolution of the cluster components: mass in primordial and processed gas separately, total ICM gas mass, and mass in galaxies.

The mid panels in Fig. 2 show the predicted abundance evolution in the ICM. Adopting galactic models with the PNJ IMF clearly improves predictions about the metallicity of the ICM.

The bottom panels in Fig. 2 show the evolution of the mass fraction of the various components of the cluster: the primordial gas, which gets consumed by galaxy formation; the processed gas, namely the gas that has been involved in galaxy formation and then re-ejected as GW; the total gas, sum of the primordial and of the processed gas; the mass in galaxies, that is in the stellar component we see today, “left over” after the GW. While in the Salpeter case (right panel) the overall mass that remains locked into galaxies (long-dashed line) is larger than the mass ejected in the GWs (dotted line), the opposite is true for the cluster model with the PNJ galaxies (left panel), as qualitatively expected from § 2. In the latter case, the mass of the re-ejected gas is  $\sim 1.5$  times larger than that locked into galaxies. Although this is not enough to account for the whole of the observed intra-cluster gas (which a mass 2–5 times larger than that in galaxies, Arnaud et al. 1992), the amount of gas re-ejected by galaxies is expected to make up for a remarkable fraction of the overall ICM.

## 5. Open issues and future perspectives

Once the model is calibrated to reproduce the observed LF in the B-band (Fig. 2, top panels), it turns out that the match with LFs in redder bands is not as good. Fig. 3 (left panel) shows the comparison to the observed LF in the R-band: the “best-case” model calibrated on the B-band seems to underestimate the number of luminous galaxies with a red stellar population. A similar effect is seen for the LF in the K-band. We used the B-band LF for the calibration, as it offered the deepest and most extensive dataset, but the LF in the red bands is probably a better track of the old stellar population responsible for the bulk of the metal enrichment, while the B-band might be sensitive to recent minor bursts of star formation. Hence, calibrating the model over the red stellar population should provide a better estimate of the galaxy formation history and of the consequent chemical enrichment of the ICM.

In particular, a larger number of old giant galaxies will help to obtain higher values of the Iron Mass to Light Ratio (IMLR, for a definition see Renzini 1997 and references therein), closer to the very high IMLRs measured in real clusters ( $\geq 0.01$ , Finoguenov, David & Ponman 2000). To illustrate this point, in the right panel of Fig. 3 we plot the present-day IMLR of individual ellipticals modelled with the PNJ IMF, as a function of the initial mass of the galaxy and for different redshifts of formation. Higher values of the IMLR pertain to more massive and older galaxies. With the PNJ IMF in fact, galaxies which are more massive and/or formed at higher redshifts, store less mass in the stellar component, while ejecting more, and more metal-rich, gas in the GW (Fig. 1 and § 2); both effects tend to enhance the corresponding IMLR.

Hence, with a galaxy formation history producing more red giant galaxies in the “cluster mixture”, as suggested by the LFs in the red bands, we expect to predict high values for the overall IMLR in the cluster.

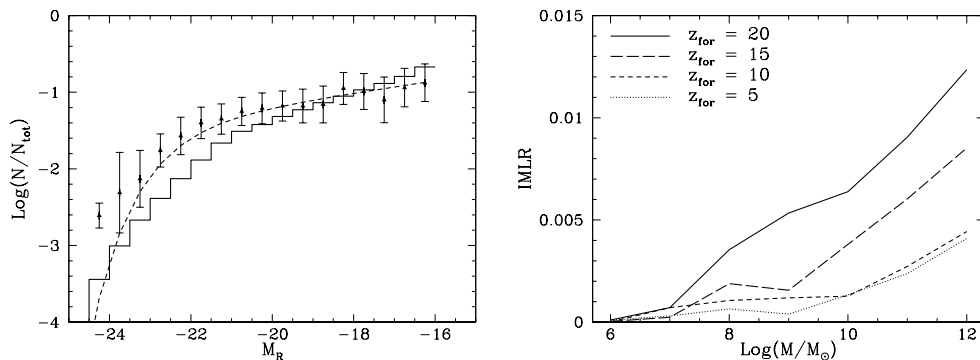


Figure 3. *Left panel:* Predicted R-band luminosity function of cluster galaxies versus the observational data (by Driver et al. 1998; the dashed line is the Schechter LF they derive from their data).

*Right panel:* Iron Mass to Light Ratio for individual ellipticals as a function of initial mass and for different redshifts of formation.

### Acknowledgments

LP and AM are grateful to F. Matteucci and to the organizers of this conference for giving them the opportunity to participate and contribute.

### References

- Arimoto N., Yoshii Y., 1987, A&A 173, 23
- Arnaud M., Rothenflug R., Boulade O., et al., 1992, A&A 254, 49
- Chiosi C., 2000, A&A 364, 423
- Chiosi C., Bressan A., Portinari L., Tantalo R., 1998, A&A 339, 355
- Driver S.P., Couch W.J., Phillips S., 1998, MNRAS 301, 369
- Elbaz D., Arnaud M., Vangioni-Flam E., 1995, A&A 303, 345
- Finoguenov A., David L.P., Ponman T.J., 2000, ApJ 544, 188
- Fukazawa Y., Makishima K., Tamura T., et al., 1998, PASJ 50, 187
- Gibson B.K., Matteucci F., 1997a, ApJ 475, 47
- Gibson B.K., Matteucci F., 1997b, MNRAS 291, L8
- Larson R.B., 1986, MNRAS 218, 409
- Loewenstein M., Mushotzky R.F., 1996, ApJ 466, 695
- Matsumoto H., Tsuru T.G., Fukazawa Y., et al., 2000, PASJ 52, 153
- Matteucci F., Gibson B.K., 1995, A&A 304, 11
- Moretti A., Portinari L., Chiosi C., 2001, in preparation
- Mushotzky R., Loewenstein M., 1997, ApJ 481, L63
- Padoan P., Nordlund A.P., Jones B.J.T., 1997, MNRAS 288, 145 (PNJ)
- Renzini A., 1997, ApJ 488, 35
- Renzini A., Ciotti L., 1993, ApJ 416, L49
- Trentham N., 1998, MNRAS 294, 193
- Zepf S.E., Silk J., 1996, ApJ 466, 114