

Galaxy evolution: the effect of dark matter on the chemical evolution of ellipticals and galaxy clusters

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Abstract. In this paper we discuss the chemical evolution of elliptical galaxies and its consequences on the evolution of the intracluster medium (ICM). We use chemical evolution models taking into account dark matter halos and compare the results with previous models where dark matter was not considered. In particular, we examine the evolution of the abundances of some relevant heavy elements such as oxygen, magnesium and iron and conclude that models including dark matter halos and an initial mass function (IMF) containing more massive stars than the Salpeter (1955) IMF, better reproduce the observed abundances of Mg and Fe both in the stellar populations and in the ICM (ASCA results). We also discuss the origin of gas in galaxy clusters and conclude that most of it should have a primordial origin.

1. Introduction

The properties of elliptical galaxies are not easy to study since we can measure only their integrated properties which contain information on several stellar populations of stars with different ages and metallicity. Unfortunately, the effects of age and metallicity upon colors and metallicity indices are difficult to disentangle. Detailed models of chemical evolution and population synthesis are therefore necessary to solve this degeneracy.

What we currently know about the properties of elliptical galaxies can be summarized as follows: most of them seem to be among the oldest objects in the universe containing old red stars, although some recent studies (Faber et al. 1995) seem to indicate that ellipticals are not all coeval. This is at variance with fact that elliptical galaxies define a fundamental plane which constrains the mass to luminosity ratio, a quantity sensitive to the age of stellar populations, to have a scatter less than 16% for ellipticals in rich clusters (Faber et al. 1987). This fact argues in favor of the ellipticals being all coeval (Renzini 1995).

Ellipticals follow the well known color-magnitude relation in the sense that their colors become redder with increasing luminosity and metallicity (Faber 1972). The average metallicity of these objects appears to be solar or higher

(Weiss et al. 1995) thus indicating that they have undergone a fast and intense star formation history perhaps interrupted by the occurrence of galactic winds.

Finally, another constraint to models of chemical evolution of ellipticals, arguing for them to be old systems, is the measured SN rate. These galaxies have only SNe of Type Ia which are believed to originate from old stars, namely white dwarfs in binary systems.

Metallicity indices of Fe and Mg seem to indicate an overabundance of α -elements relative to iron in the nuclei of elliptical galaxies and that this overabundance increases with galactic luminosity. On the other hand, the Mg/Fe ratio seems to be constant inside the same galaxy (Worthey et al. 1992; Carollo and Danziger 1994), thus indicating that the gradients of Mg and Fe inside the galaxies are roughly the same. The existence of such gradients seems to be now well established (Carollo et al. 1993) and clearly indicates that some dissipative processes have occurred during the formation of ellipticals.

Elliptical galaxies are also known to have large halos of gas emitting in the X-ray band. These halos represent an indirect indication that these galaxies should contain extended dark matter halos. Other indications of the existence of such halos comes from HI kinematics, planetary nebulae, gravitational lensing and dynamical studies (see Carollo et al. 1995 and references therein). The abundances measured by ASCA in the X-ray emitting gas indicate a very low iron abundance in disagreement with the results from stellar populations. However, the derivation of abundances from the X-ray spectra is still affected by many uncertainties, as recently discussed by Arimoto et al. (1996). Another result from ASCA, influencing the evolution of ellipticals, concerns the abundances derived for the ICM in galaxy clusters. They indicate a clear overabundance of α -elements relative to iron in the ICM (Mushotzky 1994). This result is relevant to the chemical evolution of elliptical galaxies, since they are the major contributors to the enrichment of the ICM, as we will see in the next sections.

2. The standard model of chemical evolution

The model we are going to discuss has been developed first in Matteucci and Tornambè (1987) and subsequently refined in Matteucci (1992), Matteucci and Gibson (1995) and Gibson and Matteucci (1997) where a detailed description can be found. We will only remind here that it belongs to the category of the supernovae (SNe)-driven galactic wind models. In this model, efficient star formation leads to the development of a galactic wind, once the thermal energy of the gas, due to the energy injection from SNe and stellar winds, is equal or larger than the binding energy of the gas. The star formation is assumed to stop after the occurrence of the galactic wind and the galaxy evolves passively thereafter. During this stage the only active process is the restoration of gas from the stars into the interstellar medium (ISM). The only active SNe in this phase are the Type Ia which continue exploding until the present time in agreement with the observational evidence. The model includes the most recent ideas on SN progenitors and nucleosynthesis, indicating that SNe Ia originate from long living stars whereas SNe of Type II originate from short living stars. Type Ia SNe are believed to produce roughly $\simeq 0.6M_{\odot}$ of Fe, and the SNe of Type II

roughly $\simeq 0.1M_{\odot}$ of Fe. The so-called α -elements (O, Mg, Ne, Si, etc..) are thought to be preferentially formed in Type II SNe.

2.1. Basic equations

We follow the evolution of the abundances of 13 chemical elements as described in Matteucci and Gibson (1995).

The initial mass function $\varphi(m)$ is assumed to be constant in time and expressed as a power law. We explore several prescriptions for the IMF: a) Salpeter (1955), b) Arimoto and Yoshii (1987) and c) Kroupa et al. (1993).

The star formation rate is assumed to be simply proportional to the volume gas density through a constant, the star formation efficiency. This efficiency is constant in time but is assumed to vary with the galactic mass in the sense that the efficiency decreases when the total mass increases. This is based on a suggestion from Arimoto and Yoshii (1987) that the efficiency of star formation should be inversely proportional to the dynamical timescales. This assumption is not necessarily true since we could think that the star formation efficiency may increase with galactic mass as suggested by Tinsley and Larson (1979) and Matteucci (1994) in the hypothesis of the formation of ellipticals by merging of gaseous fragments. According to these different assumptions on the star formation efficiency we can predict very different behaviours of the abundances and abundance ratios as functions of galactic mass, as we will see in the following.

The binding energy of the gas is computed by assuming that elliptical galaxies possess heavy but diffuse halos of dark matter and we follow the formulation of Bertin et al. (1992). According to these authors and Matteucci (1992) we can write the binding energy of the gas as the sum of two terms, one being the binding energy of gas due to the luminous matter and the other the binding energy of the gas due to the interaction between dark and luminous matter:

$$W = W_L + W_{LD} \quad (1)$$

$$W_L = -0.5G \frac{M_{gas}(t)M_{lum}(t)}{r_L} \quad (2)$$

$$W_{LD} = -G \frac{M_{gas}(t)M_{dark}(t)}{r_L} \tilde{W}_{LD} \quad (3)$$

$$\tilde{W}_{LD} \simeq \frac{1}{2\pi} \frac{r_L}{r_D} [1 + 1.37(\frac{r_L}{r_D})] \quad (4)$$

where M_{gas} , M_{lum} and M_{dark} are the mass of gas, the mass of luminous matter and the mass of the dark matter, respectively. The quantities r_L and r_D are the half-light radius and the the radius of the dark matter core, respectively. In the Bertin et al. (1992) formulation the ratio $\frac{r_L}{r_D}$ can vary in the interval $0.1 \rightarrow 0.45$. The case with dark matter distributed like luminous matter, although unrealistic, is represented by $\tilde{W}_{LD} = 1$.

The total mass of the galaxy is defined as:

$$M_{tot} = M_{lum} + M_{dark} \quad (5)$$

which can be written as:

$$M_{tot} = (1 + R)M_{lum} \quad (6)$$

where $R = \frac{M_{dark}}{M_{lum}}$ is the ratio between the mass of the dark and luminous component.

For the sake of simplicity we assume that every galaxy, irrespective of its luminous mass, has $R = 10$ and $\frac{r_L}{r_D} = 0.1$. This means heavy but diffuse halos of dark matter. The choice of relatively diffused dark matter halos seems to be appropriate for elliptical galaxies as shown by the models Matteucci (1992) and Matteucci and Gibson (1995) as well as by the lack of dynamical evidence for dark matter inside one or two optical radii (Carollo et al. 1995). However, we do not exclude a possible variation of the amount and/or concentration of dark matter with galactic luminosity, as it seems to be the case in spiral galaxies (Persic and Salucci 1988; Persic et al. 1996). The possibility of such variations has been already discussed by Renzini and Ciotti (1993) in order to explain the properties of the fundamental plane for ellipticals.

The thermal energy of the gas is calculated by considering both the SN and stellar wind energy injection. The contribution to the thermal energy of gas from SNe is written as:

$$E_{th_{SN}} = \int_0^t \epsilon(t - t') R_{SN}(t'') dt' \quad (7)$$

where $R_{SN}(t)$ is the SN rate (either Type I or II) and $\epsilon_{SN}(t)$ is the fraction of the initial blast wave energy which is transferred into the ISM as thermal energy and t' is the explosion time. For the particular form of $\epsilon_{SN}(t)$ see Matteucci and Gibson (1995) and Gibson and Matteucci (1997).

The contribution to the thermal energy of the gas from stellar wind is calculated according to Gibson (1994) and is written as:

$$E_{th_{SW}} = \eta \int_0^t \int_{12.0}^{M_U} \frac{\varphi(m)}{m} \epsilon_W(m, t - t', Z(t')) dm dt' \quad (8)$$

When the total thermal energy of gas is equal or larger than its binding energy, a galactic wind develops and lasts until this condition is reversed. Whether there is only an early wind episode or whether more episodes occur is a delicate point and depends crucially on the balance between the effects of the potential well and the injection of energy from stars. Clearly the presence and distribution of dark matter plays a very important role in determining the onset and the entity of galactic winds.

3. Results for elliptical galaxies

For standard model described herein the star formation efficiency decreases with galactic mass. This model predicts that more massive galaxies develop a galactic wind later than the less massive ones, the reason being that the potential

well depth increases with the total mass of the galaxy, while the efficiency of star formation decreases. This behaviour can change if one assumes that the efficiency of star formation is increasing with the total mass and one can obtain the situation where the more massive galaxies develop a galactic wind before the less massive ones. Matteucci (1994) analysed this case and referred to it as the inverse wind scenario. The reason for requiring an inverse wind situation resides in the fact that one cannot explain the increase of the $[\text{Mg}/\text{Fe}]$ ratio in the nuclei of ellipticals as a function of galactic luminosity (Worthey et al. 1992). In fact, the standard model predicts exactly the opposite behaviour, due to the winds developing later in more massive ellipticals, which drives the average $[\text{Mg}/\text{Fe}]$ downward. This “downward” trend results from the increased contribution of Fe-donating Type Ia SNe in the more massive galaxies. This behaviour is well illustrated in Figure 1 where we show the predictions of the standard model concerning the $[\text{O}/\text{Fe}]$ ratio (oxygen and magnesium should vary in lockstep) in the gas for model computed with different IMFs and different initial luminous masses. The times for the occurrence of the galactic wind is marked on each curve. From this figure it is easy to see that if the times for the occurrence of the galactic wind become shorter and shorter with increasing galactic mass, then the average $[\text{O}/\text{Fe}]$ would increase with galactic mass instead than decrease. Another possibility, in order to obtain an inverse wind situation, might be to vary the amount and/or the concentration of dark matter in a way such that the more massive galaxies would have less and/or less concentrated dark matter. This sounds like an interesting possibility, although it has not yet been calculated in detail, since it seems to happen in spiral galaxies (Persic and Salucci 1988; Persic et al. 1996) and in dwarf spheroidal galaxies (Kormendy, 1990). From this discussion it becomes evident how abundance ratios in stellar populations and gas in ellipticals can be used to constrain the amount and concentration of dark matter in these objects. Another possibility, however, could be a variable IMF from galaxy to galaxy. In this case, in fact, one does not need to have an inverse wind situation, as shown in Matteucci (1994). This possibility has also the advantage of reproducing the slight increase of the M/L_B ratio with galactic mass (Bender et al. 1992). The variation of the IMF should be such that more massive galaxies should have more massive stars relatively to less massive galaxies.

Finally, a very important feature of Figure 1 is that, independently of the assumed IMF and time for the occurrence of a galactic wind, a high $[\text{O}/\text{Fe}]$ ratio in the dominant stellar population is achieved only if the period of major star formation has been short, namely no longer than $\sim 3 \cdot 10^8$ years. This is a very strong conclusion since it implies a very fast process for the formation of big ellipticals, at variance with the hierarchical clustering scenario for galaxy formation.

Matteucci and Gibson (1995) calculated several models for ellipticals of initial luminous mass in the range $1.0 \cdot 10^9 \rightarrow 2.0 \cdot 10^{12} M_\odot$ for the three IMF cases a), b) and c). One set of models was calculated with an increasing star formation efficiency. Their results are shown in Table 1.

All of these models contain the same prescriptions about dark matter. The interesting fact is that in all the models they found only early galactic winds and this was mainly due to the presence of dark matter. The epoch for the onset of

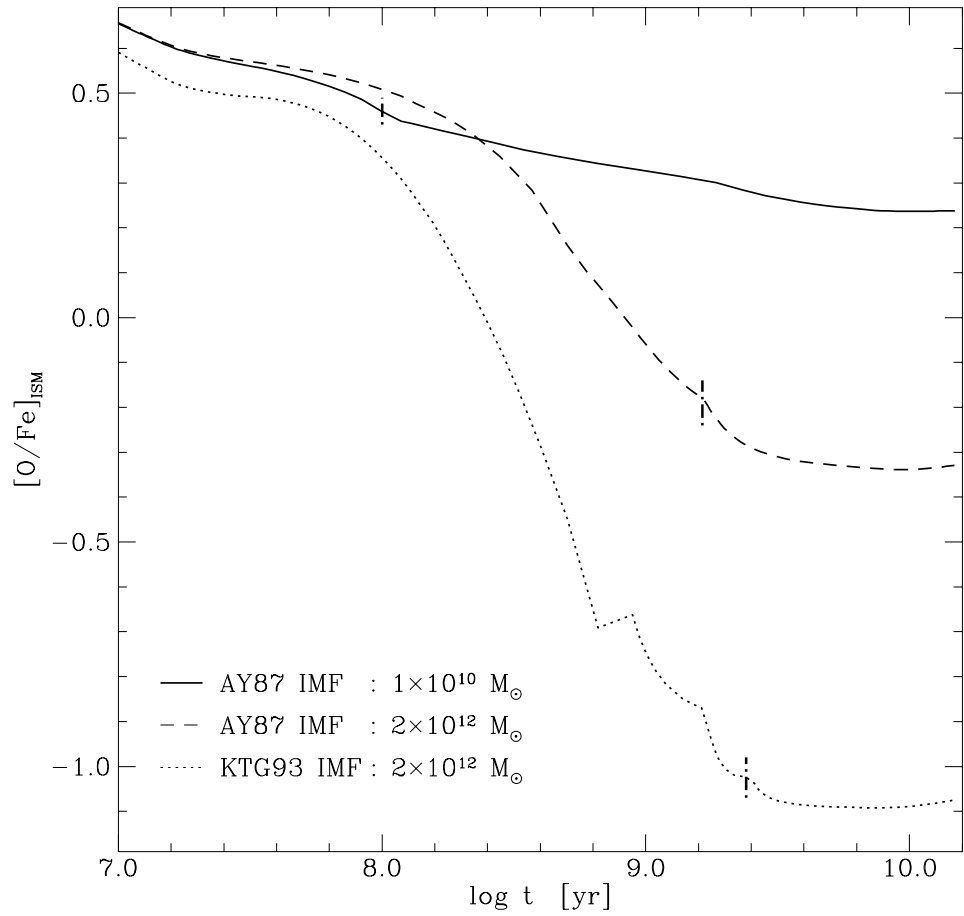


Figure 1. The [O/Fe] ratio in the gas as a function of time for galaxies of different initial luminous mass and different IMF's prescriptions: AY87=Arimoto and Yoshii (1987), KTG93=Kroupa et al. (1993)

Table 1. Predicted masses of gas and individual elements ejected by a global wind at time t_{GW} from a galaxy of initial mass $M_{\text{g}}(t \equiv 0)$. Columns 8 and 9 contain the predicted present-day SNe Type Ia rates (SNe century $^{-1}$ $10^{-10}L_{B\odot}$) and luminous mass to blue luminosity ratios, respectively. The mass-weighted mean stellar metallicity is given in column 10.

$M_{\text{g}}(0)$	t_{GW}	M_{g}^{ej}	$M_{\text{Fe}}^{\text{ej}}$	M_{O}^{ej}	$M_{\text{Mg}}^{\text{ej}}$	$M_{\text{Si}}^{\text{ej}}$	R_{SNIa}	$M_{\text{lum}}/L_{\text{B}}$	$[\text{Fe}/\text{H}]_m$
Salpeter IMF: Inverse Wind Model ($A = 0.18$)									
1.0(9)	2.21	4.50(7)	6.74(5)	1.46(6)	1.00(5)	2.38(5)	0.32	13.8	+0.11
1.0(10)	1.16	3.71(8)	4.40(6)	1.12(7)	7.11(5)	1.60(6)	0.34	14.9	-0.03
1.0(11)	0.56	1.80(9)	2.37(7)	5.95(7)	3.84(6)	8.68(6)	0.23	15.6	-0.09
1.0(12)	0.24	1.59(10)	1.33(8)	2.38(8)	1.70(7)	4.73(7)	0.08	15.9	-0.28
2.0(12)	0.19	2.94(10)	2.36(8)	5.57(8)	3.65(7)	8.96(7)	0.02	16.0	-0.28
Salpeter IMF: Classic Wind Model ($A = 0.18$)									
1.0(9)	0.06	3.48(8)	2.89(5)	5.50(6)	2.24(5)	2.45(5)	0.00	16.1	-0.78
1.0(10)	0.20	9.43(8)	3.29(6)	2.97(7)	1.46(6)	1.95(6)	0.09	16.0	-0.33
1.0(11)	0.56	1.85(9)	2.30(7)	6.86(7)	4.24(6)	8.75(6)	0.26	15.6	-0.03
1.0(12)	1.34	6.46(9)	1.40(8)	2.20(8)	1.73(7)	4.66(7)	0.30	14.8	+0.17
2.0(12)	1.80	9.79(9)	2.90(8)	3.40(8)	3.06(7)	9.24(7)	0.29	14.2	+0.26
Arimoto & Yoshii IMF: Classic Wind Model ($A = 0.05$)									
1.0(9)	0.02	7.17(8)	5.15(5)	1.23(7)	5.04(5)	4.79(5)	0.00	23.6	-0.60
1.0(10)	0.10	4.22(9)	1.15(7)	2.13(8)	1.04(7)	1.04(7)	0.00	23.5	-0.20
1.0(11)	0.55	6.57(9)	7.03(7)	5.09(8)	4.78(7)	5.26(7)	0.27	22.7	+0.29
1.0(12)	1.28	2.16(10)	3.37(8)	1.56(9)	1.78(8)	2.14(8)	0.31	21.4	+0.41
2.0(12)	1.64	3.14(10)	5.24(8)	2.22(9)	2.59(8)	3.18(8)	0.29	20.8	+0.43
Arimoto & Yoshii IMF: Classic Wind Model ($A = 0.02$)									
1.0(9)	0.02	7.17(8)	5.15(5)	1.23(7)	5.04(5)	4.79(5)	0.00	23.6	-0.60
1.0(10)	0.10	4.22(9)	1.15(7)	2.13(8)	1.04(7)	1.04(7)	0.00	23.5	-0.20
1.0(11)	0.55	6.57(9)	7.03(7)	5.09(8)	4.78(7)	5.10(7)	0.09	22.7	+0.25
1.0(12)	1.28	2.16(10)	3.37(8)	1.56(9)	1.78(8)	1.73(8)	0.11	21.3	+0.34
2.0(12)	1.64	3.14(10)	5.24(8)	2.22(9)	2.59(8)	2.66(8)	0.10	20.7	+0.36
Kroupa et al. IMF: Classic Wind Model ($A = 0.30$)									
1.0(9)	0.10	1.83(8)	2.02(5)	2.39(6)	9.79(4)	1.31(5)	0.00	8.3	-0.79
1.0(10)	0.24	5.83(8)	2.91(6)	1.18(7)	6.02(5)	1.19(6)	0.14	8.3	-0.39
1.0(11)	0.70	1.32(9)	2.41(7)	2.89(7)	2.29(6)	7.49(6)	0.20	8.0	+0.04
1.0(12)	1.87	6.15(9)	2.43(8)	1.60(8)	1.78(7)	7.14(7)	0.25	7.2	+0.31
2.0(12)	2.40	1.07(10)	4.77(8)	2.89(8)	3.40(7)	1.39(8)	0.28	6.9	+0.39

the galactic winds is shown in column 2, the duration of the wind phases varies from several 10^7 years to several 10^8 years. After the wind the galaxies evolve passively just accumulating the gas restored by all the dying stellar populations. In column 3 is shown the total mass of gas which is ejected during the wind phase, while in column 4,5,6 and 7 are shown the masses ejected in the form of Fe,O,Mg and Si. In column 8 we show the present time Type Ia SN rate in units of SNu which should be compared with the observed rate: $(0.25 \rightarrow 0.44)h^2$ SNu (Turatto et al. 1994), where $h = H_o/100$. Finally in column 9 we show the predicted M/L_B ratios and in column 10 the predicted mass-weighted average $\langle [Fe/H] \rangle$ in the dominant stellar population

4. Contribution of the ellipticals to Fe and α -elements of the ICM

Matteucci and Gibson (1995) derived power relationships between the ejected masses M_i^{ej} of gas/chemical species and the final galactic mass from the results shown in Table 1. Then they integrated these ejected masses on the cluster mass spectrum (Schechter 1976) under the assumption that mainly ellipticals and S0 galaxies contribute ejected gas to the ICM. This assumption is generally supported by the observational evidence that there is a clear correlation between the total visual luminosity of the ellipticals in clusters and the total masses of iron and gas measured in the X-ray band (Arnaud 1994). However, as we will see in the next section, there could be the possibility that dwarf galaxies, previously underestimated in clusters, contribute non-negligibly to the total gas mass in clusters. The derived integrated masses together with the predicted [O/Fe], [Si/Fe] and iron mass-to-light ratio for the clusters (IMLR) are shown in Table 2. Table 2 shows the results obtained for a typical rich and poor cluster. All the models are computed by assuming $H_o = 85 \text{ km sec}^{-1} \text{ Mpc}^{-1}$ with the exception of the classic wind model with the Arimoto and Yoshii (1987) IMF where the results for $H_o = 50 \text{ km sec}^{-1} \text{ Mpc}^{-1}$ (second row of each case) are also shown.

One of the most relevant results shown in Table 2 is the total mass of gas ejected from the ellipticals which is, in all cases, far less than observed indicating that the majority of the ICM should have a primordial origin. This conclusion had already been reached by Matteucci and Vettolani (1988) but in this case the discrepancy with the observed total gas masses is even stronger since, due to the presence of dark matter halos, the galaxies do not eject all of their available gas as it was the case in the Matteucci and Vettolani (1988) models. Therefore, the presence of dark matter in galaxies has important consequences also for the interpretation of the origin of the ICM as we will see even better in the next section. Another important result is the predicted [O/Fe] ratio in the ICM. Recent ASCA data suggest that [O/Fe] is high and positive ($0.1 \rightarrow 0.7$, Mushotzky 1994). From Table 2 we can see that only models with a flat IMF (case b) can reproduce the observed values. It is worth noting that the existence of only early winds is also a necessary, although not sufficient, condition to achieve this situation. In fact, if all the gas restored by stars is allowed to eventually be lost, the resulting [O/Fe] ratio in the ICM is low and negative as a result of the continuous injection of Fe from SNe of Type Ia, as it was the case in Matteucci and Vettolani(1988)'s model. Abundance ratios in the ICM are therefore an extremely useful and tight constraint to understand the evolution

Table 2. Predicted total mass of gas and elements ejected into the intracluster medium (ICM) from all cluster ellipticals and lenticulars, and ICM Iron Mass-to-Light Ratios (IMLRs), [O/Fe] and [Si/Fe] ratios.

$M_{\text{g,tot}}$	$M_{\text{Fe,tot}}$	$M_{\text{O,tot}}$	$M_{\text{Mg,tot}}$	$M_{\text{Si,tot}}$	IMLR	[O/Fe]	[Si/Fe]
Salpeter IMF: Inverse Wind Model							
<i>Rich Cluster</i>							
3.83(12)	3.81(10)	8.60(10)	5.34(9)	2.16(10)	0.002	-0.46	-0.17
<i>Poor Cluster</i>							
1.13(11)	1.17(9)	2.64(9)	1.64(8)	6.57(8)	0.002	-0.45	-0.18
Salpeter IMF: Classic Wind Model							
<i>Rich Cluster</i>							
4.76(12)	4.04(10)	1.10(11)	6.90(9)	1.94(10)	0.002	-0.37	-0.25
<i>Poor Cluster</i>							
1.68(11)	1.19(9)	3.77(9)	2.28(8)	6.05(8)	0.003	-0.30	-0.22
Arimoto & Yoshii IMF: Classic Wind Model							
<i>Rich Cluster</i>							
1.85(13)	1.10(11)	8.59(11)	7.07(10)	1.15(11)	0.006	+0.08	+0.09
1.44(13)	4.18(10)	5.52(11)	3.26(10)	3.64(10)	0.005	+0.31	+0.19
<i>Poor Cluster</i>							
6.57(11)	3.38(9)	2.88(10)	2.24(9)	3.60(9)	0.006	+0.12	+0.10
1.03(12)	2.62(9)	3.72(10)	2.08(9)	2.30(9)	0.006	+0.34	+0.19
Kroupa et al. IMF: Classic Wind Model							
<i>Rich Cluster</i>							
2.37(12)	4.12(10)	5.17(10)	3.66(9)	1.48(10)	0.003	-0.71	-0.38
<i>Poor Cluster</i>							
8.07(10)	1.13(9)	1.70(9)	1.13(8)	4.26(8)	0.003	-0.63	-0.36

of ellipticals. However, before drawing firm conclusions we should be confident of the abundances derived from the X-ray spectra, whereas the situation is not yet clear as already mentioned before.

5. More on the source of the ICM gas

While the bright and intermediate part of the luminosity function of a cluster is consistent with a slope $\alpha \simeq -1.25 \rightarrow -1.45$ (Ferguson and Sandage, 1995), there are recent indications that the faint-end slope ($M_B \geq -15.0$) of the luminosity function may be significantly steeper ($\alpha \sim -1.8 \rightarrow -2.2$, De Propris et al. 1995). Trentham (1994) suggested that, if the faint-end slope of the luminosity function is taken into account, we can explain all the gas in clusters as due to galaxies and in particular to dwarfs.

In particular, in order to achieve this, one has to assume that each galaxy, irrespective of its mass, loses a fraction of its total mass (luminous+dark) of the order of $\gamma = 0.33$. The range of galactic masses contributing to the gas being $10^4 - 10^{11} M_\odot$ and the slope of the faint- end of the luminosity function being in the range $\alpha = -1.4 \rightarrow -1.7$. Under these prescriptions he was able to account for all the gas in clusters as due to galaxies, but he predicted for dwarf galaxies $M/L \propto L^{-0.42 \rightarrow -0.27}$ not in very good agreement with the observational estimate. Kormendy (1990), in fact, suggests that the exponent of this law for dwarf galaxies is $\beta \sim -0.13 \rightarrow -0.31$. This exponent β measures how rapidly dwarf galaxies become dark matter dominated as their luminosity decreases. Later, Nath and Chiba (1995) calculated more realistic γ values varying with galactic

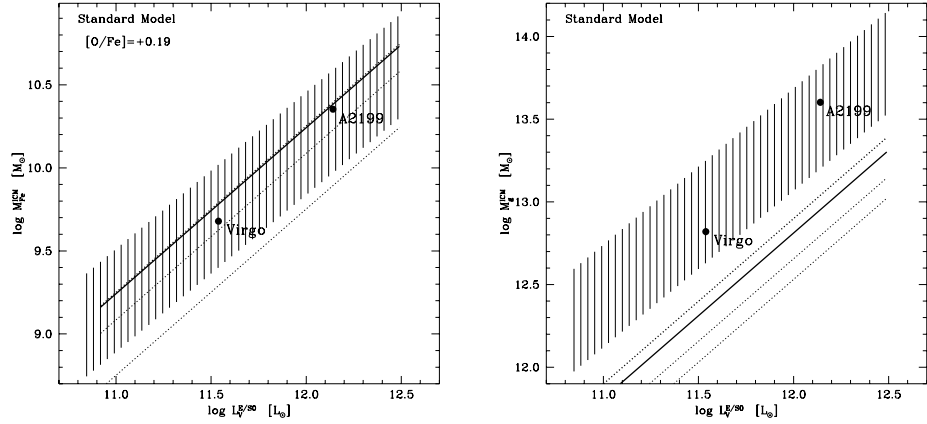


Figure 2. Shaded region shows the observed correlation between the non-spiral- originating V-band cluster luminosity, and the observed ICM iron mass (left figure) and gas mass (right figure) after Arnaud (1994). Solid curve is a single luminosity function model of slope $\alpha = -1.45$. Dotted lines are the components of a two slope luminosity function model-the lower curve is the low luminosity dwarf spheroidal component with $\alpha = -1.9$. The middle one is the normal giant spheroidal population with $\alpha = -1.45$. The heavy dotted curve is their sum.

mass and found that in order to explain all the gas in clusters as due to dwarfs one needs to assume $\alpha \sim -1.7 \rightarrow -1.9$, thus obtaining a $\beta \sim -0.55 \rightarrow -0.37$, totally outside the observed range. Therefore, they showed that more realistic assumptions weaken the argument of Trentham (1994). Recently, Gibson and Matteucci (1997) extended the model for elliptical galaxies described before to dwarf spheroidal galaxies, included updated physical inputs and calculated the total contribution to the gas and metal of the ICM from dwarf and giant elliptical galaxies. These authors calculated also the photometric evolution (see Gibson 1996 for details) of the considered galaxies in order to have a larger number of constraints to compare with the results and took into account the extreme case where all the gas produced by stars, after the early wind phase, is eventually lost. They found that the simple suggestion of Trentham (1994) about the amount of mass which should be ejected by each galaxy is extremely unrealistic. In order to reproduce realistic galaxies, namely with the right colors and luminosities, they found $\gamma \sim 0.04 \rightarrow 0.08$. They used a slope for the faint end of the luminosity function $\alpha=-1.9$. Their results indicate that also under these extreme conditions and for any reasonable choice of the main parameters is not possible to explain all of the gas in clusters as due to galaxies. In particular, they found that the contribution of dwarfs to the total gas is not negligible and it raises the galactic contribution up to 35% to compare with the negligible amount of galactic gas obtained by Matteucci and Gibson (1995) by considering only normal ellipticals. In Figures 2 and 3 we show the predicted total masses of iron and gas as functions of the total visual luminosity of the cluster galaxies

compared with the data from Arnaud (1994). From these figures it is clear that the contribution of dwarfs to the gas is not negligible whereas their contribution to metals is negligible. This conclusion is in agreement with Nath and Chiba (1995) who also showed that dwarfs contribute negligibly to the iron content in clusters.

Finally, we would like to stress the fact that this result about the origin of gas in clusters is quite robust. In fact, Gibson and Matteucci (1997) have chosen the most favorable conditions for the galaxies to loose mass. In particular, they assumed that the amount and concentration of dark matter in dwarfs is constant thus underestimating their potential well. The β value that they predict is, in fact, $\beta = -0.07$, lower than the observed range.

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