# The Metallicity Gradient of the Old Halo

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**Abstract:** We present a model of globular cluster (GC) self-enrichment. In this model, the final metallicity depends on the pressure exerted by the hot protogalactic medium on the proto-globular cluster clouds (PGCCs) and consequently on their location in the protogalaxy. Our model is therefore able to explain the metallicity gradient observed in the Old Halo globular cluster subsystem.

## 1 Introduction

One of the main argument used against the hypothesis of self-enrichment in GCs is the supernova energetics, namely the ability of a small number of supernovae to disrupt PGCCs. However, with a simple self-enrichment model, Parmentier *et al.* (Section 5, this meeting) have shown that this idea may not be true, because only a fraction of the kinetic energy of the Type II supernova ejecta is deposited as kinetic energy of the ISM. The kinetic energy of the supershell, pushed by several tens or even hundreds of SNeII, can be less than the binding energy of the PGCC once the shell has reached the edge of the PGCC. We now go a step further and investigate an important consequence of this self-enrichment model.

## 2 GC Formation Through Supershell Phenomenon

Dopita and Smith (1986) and Parmentier et al. (1999) suggest that a more realistic way to analyse the potential disruptive effect of SNeII on the PGCCs would be to compare the binding energy of the cloud with the kinetic energy of the shell when the whole cloud has just been swept up. This criterion for disruption leads to a relation between the mass $M$ of a PGCC and the maximum number $N$ of SNeII it can sustain :

$$0.8\chi^{-3/2}M_6 + 0.6\chi^{-1/2}M_6^{1/3} + 0.2\chi^{-3/2}M_6 = 3.3\chi M_6^{-2/3}\frac{NE_{51}}{\Delta t_6}. \qquad (1)$$

$\chi$ is a parameter related to the pressure of the hot protogalactic background. We scale the PGCC mass by the Bonner-Ebert critical mass. The mass $M$ is therefore related to the external pressure by

$$M_{BE} = 1.2c^4G^{-1.5}P_h^{-0.5} \qquad (2)$$

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where $c$ is the sound speed in the cloud material. For instance, an external pressure of $2.5 \times 10^{-10}$dyne.cm$^{-2}$ leads to a cloud mass of $10^6 M_\odot$ and this cloud can sustain more than 300 supernovae.
To check that such a number of SNe is able to enrich the primordial gas of the cloud up to metallicities typical of the galactic halo, we have derived a relation between the number of SNeII, the mass of primordial gas and the metallicity :

$$[\frac{Fe}{H}] = -1.5 + log\frac{N}{280M_6}. \tag{3}$$

In this relation, we assume that the mass distribution of the stars obeys a Salpeter IMF and that all supernovae whose mass $m$ is between 12 and 60 M$_\odot$ release a mass $m_z = 0.3m - 3.5$ (in units of M$_\odot$) of heavy elements. The *total* number $N$ of supernovae also takes into account those whose mass is between 9 and 12 M$_\odot$. Hence, under the external pressure mentioned above, a metallicity of about $-1.5$ can be reached. As shown in Tab. 1, the self-enrichment level depends on the background pressure and therefore on the location of the PGCC in the Protogalaxy. If the value of the pressure exerted by the hot background on the PGCC increases, namely if the PGCC is located deeper in the Protogalaxy, the self-enrichment level allowed by the dynamical constraint increases. Therefore, *this model implies a metallicity gradient in the Galactic Halo.* Equations (1), (2) and (3) lead to a relation between the metallicity and the local value of the hot protogalactic background pressure :

Table 1: Dependence of [Fe/H] on $P_h$ for PGCCs in equilibrium

| $P_h[dyne.cm^{-2}]$ | $\chi$ | $log_{10}M_{BE}/M_\odot$ | [Fe/H] |
|---|---|---|---|
| $1.1\ 10^{-9}$ | 0.15 | 5.7 | -1.08 |
| $1.4\ 10^{-10}$ | 0.30 | 6.2 | -1.52 |
| $4.1\ 10^{-11}$ | 0.45 | 6.4 | -1.79 |
| $1.7\ 10^{-11}$ | 0.60 | 6.6 | -1.98 |

$$[\mathrm{Fe/H}] = 3.4 + 0.5\mathrm{logP_h} \tag{4}$$

With an adopted distribution of $P_h$ vs the galactocentric distance D, we can now deduce the metallicity gradient set when GCs were formed. Assuming the model of Murray and Lin (1992) for the pressure profile of the hot protogalactic background $P_h = 1.25 \times 10^{-9} D_{kpc}^{-2}$, the previous relation becomes :

$$[\mathrm{Fe/H}] = -1 - \mathrm{logD_{kpc}}. \tag{5}$$

Is this gradient in accordance with the observational situation ?

# 3 What Is Observed ?

The whole Galactic Halo exhibits only a very weak metallicity gradient with the galactocentric distance D (Fig. 1, based on Harris, 1996). However, according to Lee et al. (1994) and Zinn (1992), the Halo could be composed of two subpopulations : the Old Halo and the Younger Halo. The main differences between them are

1. The location : the Younger Halo GCs are mostly located in the outer part of the Halo (outside 10kpc, see Fig. 1);

2. The horizontal branch morphology : for the same [Fe/H], the horizontal branch of the Younger Halo GCs is redder. This is the $2^{nd}$ parameter problem, whose solution is probably the age even if a third parameter is not excluded;

3. The kinematics and the orbit shapes : on average, the Younger Halo GCs presents smaller rotation velocity (perhaps even retrograde), higher orbital energy, higher apogalactic distances and higher excentricities (Dinescu et al. 1999).

Therefore, the Younger Halo would constitute a younger population of GCs, hotter from the dynamical point of view and lying in the outer regions of the Galactic Halo.

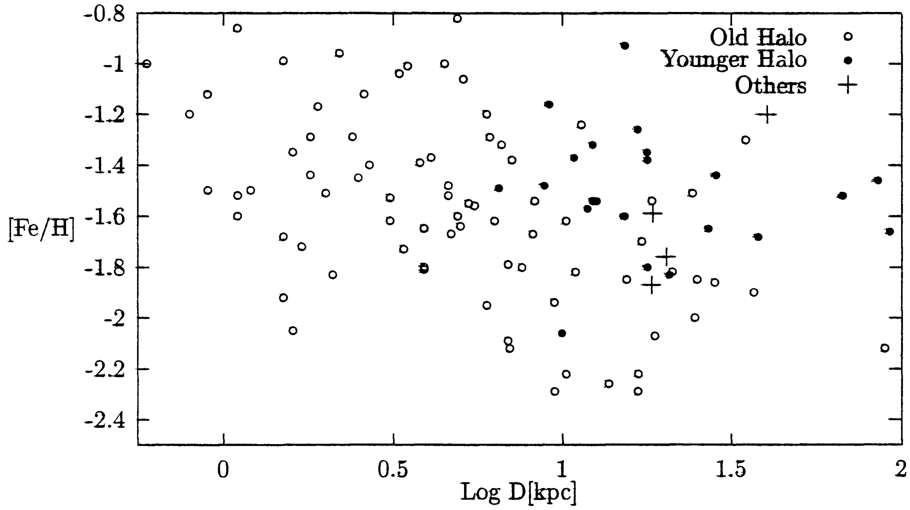

Figure 1: The whole Galactic Halo includes two subpopulations, the Old Halo and the Younger Halo. The + ("Others") represent the GCs related to the dwarf galaxy Sagitarius currently disrupted by the galactic tidal effects

To explain these differences, Zinn (1992) has proposed the following scheme :

- ◇ The Old Halo have been formed during the dissipative collapse of the protogalactic cloud;
- ◇ The Younger Halo consists in clusters formed around satellite systems that were accreted and disrupted by the Milky Way. Their GCs has therefore been added to the genuine galactic GCs. Such an example of "contamination" currently occurs : Sagittarius A is disrupted by the galactic tidal field and its globular clusters (M54, Arp2, Ter7, Ter8) are incorporated in the halo.

Therefore, the self-enrichment model must be applied to the Old Halo only. From the point of view of the metallicity distribution, this halo subdivision into 2 groups is important. While the Younger Halo shows no metallicity gradient at all, the Old Halo exhibits a significant one.

The metallicity distribution with galactocentric distances D of the Old Halo GCs and the theoretical model $[Fe/H] = -1 - logD_{kpc}$ are shown in Fig. 2. The slopes of the observational data distribution and of our self-enrichment model are in good agreement. The high dispersion around the theoretical model can be easily explained. Indeed, one must keep in mind that while our model predicts a relation between the metallicity of globular clusters and the galactocentric

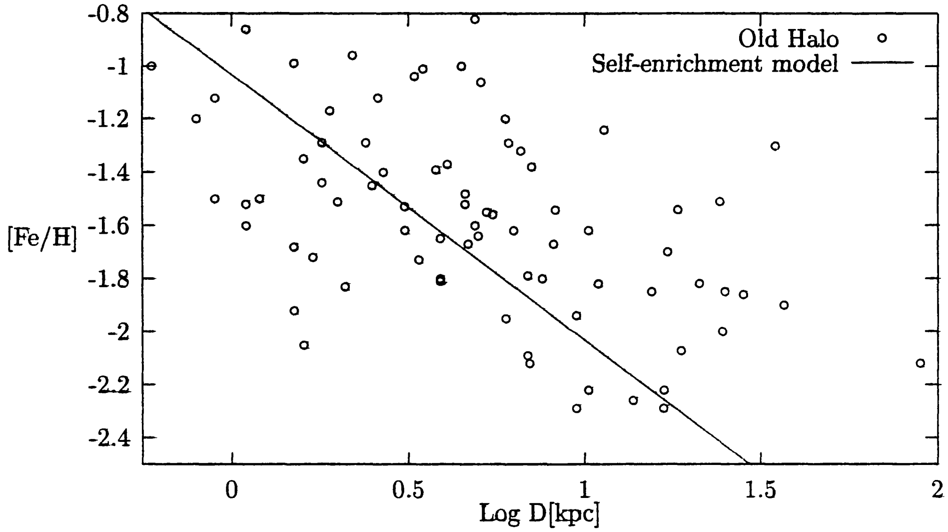

Figure 2: Comparison between the model and the metallicity gradient observed in the Old Halo

distance of their *formation site*, the observations provide their [Fe/H] vs their *current location* in the Galactic Halo.

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## References

Dinescu, D.I., Girard, T.M., Van Altena, W.F., 1999, AJ 117, 1792
Dopita M.A., Smith G.H., 1986, ApJ 304, 283
Harris W.E., 1996, AJ 112, 1487
Lee Y.W., Demarque, P., Zinn R., 1994, ApJ 423, 248
Murray S.D., Lin D.N.C., 1992, ApJ 400, 265
Parmentier G., Jehin E., Magain P., Neuforge C., Noels A. and A.A. Thoul, 1999, accepted for publication in A&A
Zinn, R., 1992, Graeme H. Smith, Jean P.Brodie, eds, ASP Conference Series, Volume 48, The globular clusters-galaxy connection, p 38