GRAVITATIONAL SEPARATION OF ELEMENTS DURING CERTAIN STAGES OF GALACTIC EVOLUTION

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INTRODUCTION

Heavy metal content is, apart from the kinematical behaviour, one of the important parameters of the population characteristics of stars. Spectroscopic observations of some galaxies including our own give the evidence for the gradient of heavy elements abundances towards the galactic center and the galactic plane (Peimbert 1975, Van den Bergh 1975 - review papers). Simultaneously several authors (Kuroczkin 1974, Khokhlova 1976) found that the deficiency (or enrichment) increase with the mass number of the element.

It seemed to be very interesting to see, if the gravitational separation of elements in the simple process of the mechanical diffusion could lead to such a situation. An attempt has been undertaken to examine the efficiency of this mechanism during some phases of galactic evolution. As far as we know, diffusion could be responsible, at least partially, for the abundance anomalies in the atmospheres of a group of stars (for example: Aller and Chapman 1960, Schatzmann 1969, Michaud 1970 etc).

After some preliminary estimations of the diffusion effects in a simple model of our Galaxy in the vicinity of the Sun (Basinska and Iwanowska 1974, Basinska-Grzesik 1974) I started to examine the conditions for the gravitational separation of elements in : a) some different regions and evolutionary phases of our Galaxy, b) in other galaxies.

In what follows are presented the results for the simplified models

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of the protoglobulars, of the spherical protogalaxies (including the spherical component of our own Galaxy) and for the column of gas perpendicular to the galactic plane in the solar neighbourhood.

ASSUMPTIONS

Velocities of diffusion were calculated using the approximate formulae (Chapman and Cowling 1970, Ferziger and Kaper 1972) :

$$\vec{v}_1-\vec{v}_2 = -D_{12}\left\{(\nabla \ln n_1-\nabla \ln n_2) + k_p \nabla \ln p + k_F(\vec{F}_1-\vec{F}_2) + k_T \nabla \ln T\right\} \qquad (1)$$

where : $\vec{v}_1$, $\vec{v}_2$ - velocities of the constituents of the two-component mixture,

n_1, n_2 - number densities of the relevant particles,

p - pressure,

T - temperature,

k_p, k_F, k_T - coefficients of the pressure, forced and thermal diffusion,

D_{12} - coefficient of the diffusion.

For neutral matter the model of the rigid spherical elastic particles was used, for ionized one - interactions between the particles proportional to the reciprocal of the distance were applied.

The calculations were made for the mixture of hydrogen and iron, since iron is the most abundant element much more heavier than hydrogen. Then it was possible to assume that : 1) iron is the trace constituent, 2) there is a hydrostatic equilibrium, 3) only gravitational or electrostatic forces are present, 4) thermodiffusion is negligible, 5) diffusion as the result of composition gradient is not important. This last statement was tested in the course of the calculations.

Now the velocity of gravitational separation of iron atoms in respect to hydrogen atoms takes the form :

$$v_{sep} = D_{12}\, k_p\, \nabla \ln p \qquad (2)$$

The changes of the iron abundance were calculated numerically solving the equation of continuity for iron atoms :

$$\partial n_2/\partial t + \mathrm{div}\,(n_2\, \vec{v}_{sep}) = 0 \qquad (3)$$

with the following boundary conditions :

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$$\ln n_2/n - \vec{v}_{sep} = 0 \quad \text{at the center}$$

$$\vec{v}_{sep} \to 0 \quad \text{at the outer boundary.}$$

MODELS

For the models of protoglobulars and spherical protogalaxies before star formation I assumed the polytropic distributions of the density. I used the polytropes of the index N = 1 for low density concentration and of the index N = 5 for the models of high density concentration.

Protoglobulars

model No	mass $M/M_\odot$	radius pc
1, 1a	10^4	10
2, 2a	10^5	33

Protogalaxies

model No	mass $M/M_\odot$	radius pc
3, 3a	10^{10}	3×10^4
4, 4a	10^{11}	10^5

Models with the index a are those corresponding to the polytropes of N = 1.

Estimating the effects of diffusion for the column of gas perpendicular to the galactic plane in the solar neighbourhood I assumed that : 1) star formation rate is proportional to the gas density, 2) the distribution of matter is as proposed by Falgarone and Lequeux (1973) with the assumption of Gaussian distribution functions for the cloud and intercloud hydrogen.

	number density of H atoms in the galactic plane	height scale
clouds	0.29 cm-3	105 pc
intercloud matter	0.155 cm-3	186 pc

The calculations were made for the intercloud matter with the simplifying assumptions : 1) gravitational acceleration is independent of time, 2) the turbulence is negligible, 3) the intercloud medium is mostly neutral. The nucleosynthesis was not taken into account.

All the estimations were made backward starting from present day conditions.

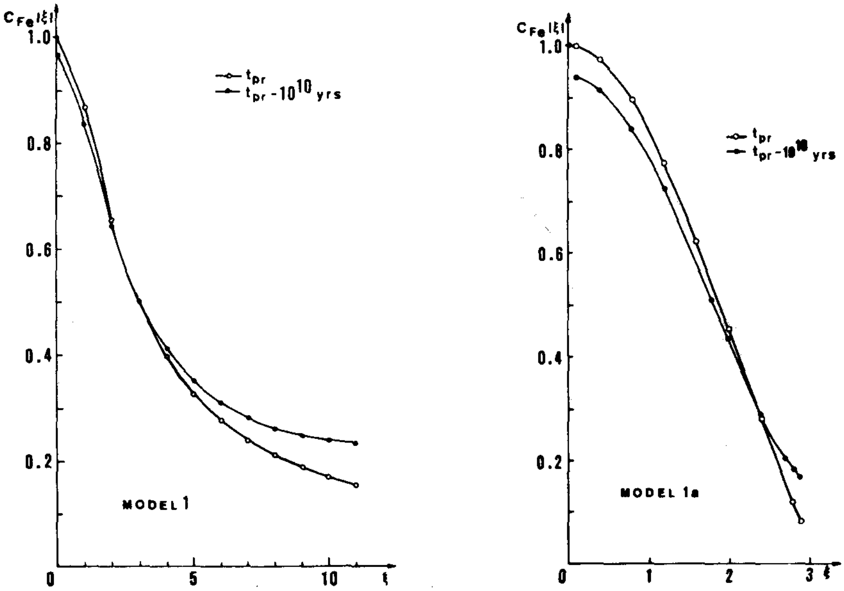

Figure 1. The distribution of the iron to hydrogen ratio C_{Fe} (ξ) in the function of the undimensional radius for the model 1 (at the left) and for the model 1a (at the right). $C_{Fe}(\xi)$ is normalized to unity for $t = t_{pr}$.

RESULTS

-Protoglobulars

The effects of the gravitational separation for the model 1 (high concentration of density) are illustrated in Fig. 1. The open circle-line shows the present distribution of the iron to hydrogen ratio as the function of undimensional radius ξ, full dot-line - the calculated ratio 10 billion years ago. The analogous results for the model 1a (low density concentration) are presented at the right part of Fig. 1. For more massive models I got smaller effects.

The changes of the iron abundance are small in the central regions, but higher (up to 50 % after 10 billion years) in the outer parts. Although these changes are not so important, the effect of gravitational separation of elements could contribute to some observed facts :

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1) Gravitational separation of elements leads to the chemical composition gradient within the cluster - there is an observational evidence for such effects (Freeman and Rodgers 1976, Kukarkin 1970, Claria and Stock 1977).

2) Comparing the changes of the iron to hydrogen ratio in models of different concentration index one can notice, that in the higher concentrated models the enriched matter (depleted, if we calculated forward) takes much bigger volume than in the low concentrated models. So cluster of higher concentration of matter would appear to be more deficient in heavy elements than the clusters of lower concentration.

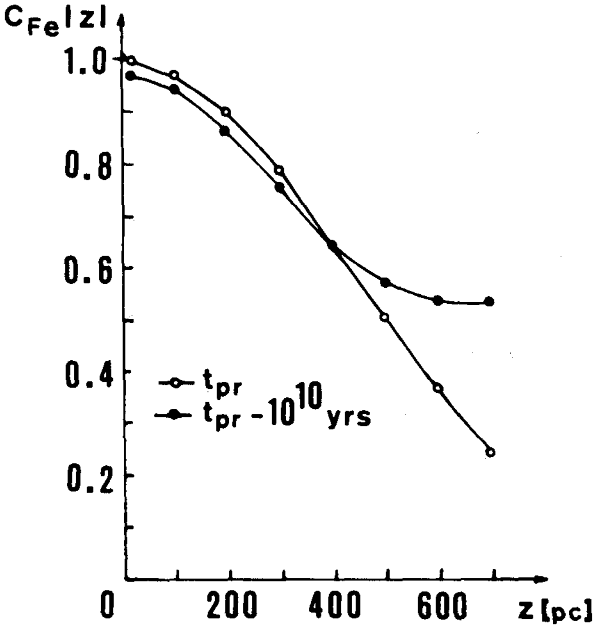

Figure 2. The distribution of the iron to hydrogen ratio $C_{Fe}(z)$ as the function of the height over the galactic plane in the vicinity of the Sun.

- Spherical Protogalaxies

The changes of the iron to hydrogen ratio during two billion years do not exceed 1 %.

Column of the gas perpendicular to the galactic plane in the solar neighbourhood.

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Fig. 2 illustrates the distribution of the iron to hydrogen ratio at the present epoch (open circles) and ten billion years ago (full dots).

During ten billion years 73 % of the intercloud matter was depleted (enriched if we calculated forward). The role of the clouds could be very effective in destroying the abundance gradient near the galactic plane, but in the outer regions containing about 8 % of the whole gas, their role could be neglected.

SUMMARY

Generally, effects of gravitational separation of the iron atoms with respect to hydrogen are rather small. They are quite negligible in the models of large ionized protogalaxies, but in the formation of globular clusters or at the stage of slow star formation in the halo-disk galaxies the process of diffusion can contribute to the change of the heavy metal content in the outer low density regions.

One could suspect that the simple process of sedimentation under gravitational forces (or some external forces of the potential character) could be very effective in the almost empty intergalactic space on one side, and on the other in very compact objects where the large gravitational forces should be taken into account (for instance in the vicinity of black holes or in some unknown remnants of the Big Bang).

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