THE CHEMICAL EVOLUTION OF A SPIRAL GALAXY DISKS

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Abstract. The results of computing the evolution of a disk subsystem of a spiral galaxy taking into account radial gradients of chemical elements (D, 4He, 12C, 13C, 14N, 16O, 7Li, Fe) are presented. It is shown that flow of intergalactic matter accreting on to the galaxy results in smoothing the radial gradients of gas and chemical elements, especially at the latest stage of the evolution. The final gradients depend weakly on the age of the galaxy and value of the Hubble constant $h$. The best agreement between calculated and observed abundance of 4He is revealed if the primordial yield is $Y_0 = 0.25$. The small decrease of the primordial deuterium abundance confirms the conclusion that the baryon density parameter is small: $\Omega_b h^2 \lessapprox 1$. Therefore, the nature of dark matter should be non-baryonic.

1. Introduction

A theoretical simulation of the primordial chemical composition changing produced in galaxies permits to determine the abundance of hydrogen, helium, and lithium in primordial substance. Hence, more adequate conclusions about physical conditions in the early universe can be drawn. The quality of these models can be improved with increasing the number of model characteristics and parameters, which can be compared with the observed ones.

At the present time, there are the serious arguments for the open galaxy model, where inflow of intergalactic matter on to the galaxy leads to smoothing the changes of interstellar chemical composition due to ejection of stellar matter enriched by heavy elements. So, the changes of primordial abundances of light elements up to the present moment turn out to be little: for deuterium $X^0(D)/X(D) = 2 - 3$ and for helium-4 $\Delta Y = Y - Y_0 = 0.02 - 0.04$, that is in a good agreement with results of nucleosynthesis in the standard Big-Bang model with small baryon density parameter $\Omega_b = \rho_b/\rho_{cr} \lessapprox 0.1$ (Yang et al., 1984). At the same time, simulation of galaxy chemical evolution requires a rather fine knowledge of parameters and functions defining this process. First of all, there are the star-formation rate, the rate of accretion on to galaxy and the initial mass function (Tosi, 1988). Further refining the forms of these functions is possible proceeding from observed information only, which is most broad for our Galaxy. So just our Galaxy is used in the present work as an empirical basis to test the results of the model computations.

On the other hand, recently a lot of the new observed data concerned with the evolution of various galaxies appear. At first, observations of helium in young galaxies show that it primordial abundance $Y_0 = 0.25$ produced in the primordial nucleosynthesis with baryon density parameter $\Omega_b = 0.05 - 0.1$ and number of neutrino flavors $N_\nu = 3$ is, apparently, overestimated, and actually $Y_0 = 0.023 \pm 0.01$ (Lequeux et al., 1979; Pagel, 1989). This fact leads to the necessity of reconsideration of the evolution...
of this element in galaxies; particularly, the value of ratio of helium – heavy elements produced in a galaxy $\Delta Y/\Delta Z = 1.5-3.5$ (Peimbert, 1986; Chuvenkov and Vainer, 1989) should be increased. Secondly, the observation of deuterated molecules near the galaxy center leads to the value $D/H = 10^{-5}$ (Lubowich et al., 1989), that significantly decreases the probability of a large inclination of the positive deuterium gradient, established by Penzias (1979). Therefore, a realistic model of galaxy chemical evolution must be both compatible with these data and explain observations of other light and heavy elements in galaxies.

Earlier, in the cycle of works (Chuvenkov and Vainer, 1989; Vainer et al., 1991) we consider the chemical evolution of galaxies as non-subdivided systems with integral characteristics. In addition, in the present work we try to calculate the radial gradients of chemical composition of matter, the distributions of gas and stars in the galaxy proceeding from the same model approaches as in the previous work.

As a result of computing the abundances of light elements ($D$, $^4$He, $^7$Li), CNO- and Fe-elements the following results are obtained: (i) the factor of deuterium depletion in the galaxy is not more than 2; (ii) the primordial helium abundance should be $\approx 0.25$; (iii) accretion on to the galaxy smooths the radial gradients of chemical elements in it; (iv) final results depend weakly on the galaxy age in the interval 13.5–20 Gyr. In general, these results confirm one more time our previous conclusions that the baryon density is small ($\Omega_b \leq 0.1$) and the nature of dark matter is non-baryonic.

Our model approximations are described in Section 2, the results are presented in Section 3, and the conclusions of the work are made in Section 4.

2. Model of the Galaxy

Let us consider the evolution of the disk subsystem of the spiral galaxy, taking into account star formation and matter exchange between disk and intergalactic surroundings. The initial disk mass is assumed to be equal to the mass of intergalactic gas normalized to one galaxy (Sarazin, 1988). Under our model approximations, the evolution of radial distribution of gas surface density in a galaxy is described by equation

$$\frac{d}{dt} G(R, t) = - \Psi(R, t) + J(R, t) - E(R, t) + A(R, t),$$  \hspace{1cm} (1)

where $\Psi(R, t)$ is the star-formation rate (SFR), $E(R, t)$ is the rate of matter ejection into intergalactic medium (IGM), $A(R, t)$ is the rate of matter accretion on to the galaxy, $J(R, t)$ is the rate of returning of the stellar matter into interstellar medium (ISM):

$$J(R, t) = \int_0^\infty E_s(m)\Psi(R, t - \tau(m))\phi(m, t - \tau(m)) \, dm,$$  \hspace{1cm} (2)

where $E_s(m)$ is the share of stellar mass returned to ISM by a star with mass $m$ after completion of its evolution; $\phi(m, t - \tau(m))$ is the initial mass function (IMF), $m$ is expressed in solar units.