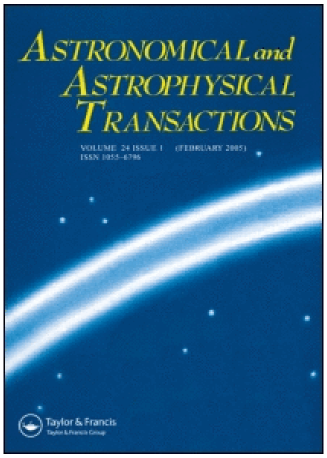

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FORMATION OF PRIMORDIAL LUMINOUS OBJECTS IN VIRIALIZING HALOS

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In the framework of a simplified description we analyze the question of how shock waves, possibly formed in the process of virialization of dark matter halos, affect evolution of low-mass baryonic condensations. We argue that such shock waves initiate fluctuations of temperature and associated variations in fractional ionization, which in turn can diminish the minimal mass of the first luminous objects by factor of 30.

Keywords: Cosmology-theory; Early Universe; Galaxies-Formation

1 INTRODUCTION

In the standard cold dark matter (CDM) model the first luminous (Population III) objects are born during the collapse of baryons in gravitational potential of dark matter, which forms the so-called dark halos settled through violent relaxation to a virial state [1]. Baryonic component virializes via associated random hydrodynamic shocks, with Mach numbers larger than the virial value $\mathcal{M} = 1$. Gas processed through sufficiently strong shocks may have temperature substantially higher than the virial value, and consequently can become highly ionized. This gas, when being mixed with the rest of baryons will change their chemistry and thermal regime. Here we focus mainly on how such highly ionized gas can affect the lower limit of the Population III masses. Other aspects and consequences are described in detail in [2].

2 MODEL

We assume here that a halo of mass $M_h = {\Omega_b}^{-1}M$, M is the baryon mass, relaxes to its virial state through tidal interactions and direct collisions of clumps or subhalos of smaller baryon masses m_i, such that $\sum_i m_i = \delta M$, $\delta < 1$. We further assume that the shocks increase temperature of baryons in clumps to the level $T(m_i)$ depending on their relative velocities and other details of the interactions. Then, after virialization the average temperature

$$T_v = \frac{1}{M}\sum_i m_i T(m_i), \tag{1}$$

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is established, with T_v being the virial temperature corresponding to mass M. In order to simplify the description, in this contribution we will assume that all the shocks have equal Mach numbers and $T(m_i) = T_s$, such that $T_v = \delta T_s$. Because of a very strong temperature dependence of the collisional ionization rate of hydrogen, $\propto \exp(-15.78/T_4)$, even relatively small variations in T_s around 10^4 K can result in large variations of fractional ionization behind such shocks. For a head-on collision of two baryonic clumps of $10^3 M_\odot$ (the corresponding subhalo mass $10^3 \Omega_b^{-1} M_\odot$) at $z \sim 100$ with velocities of $\simeq 14\,\mathrm{km\,s^{-1}}$, the time required for the fractional ionization to grow from its cosmological value up to $x = 0.9$ is $\tau_{0.9} \simeq 1.5 \times 10^{12}$ s, much shorter than dynamical time $\tau_d \sim 2 \times 10^{13}$ s. Note, however, that for velocities $\simeq 10\,\mathrm{km\,s^{-1}}$ $\tau_{0.9}$ increases by five orders of magnitude. Thus, for a sufficiently strong shock we can assume ionization equilibrium described by Elvert equation

$$\frac{x_s}{1 - x_s} \simeq 6 T_s e^{-15.78/T_{s4}}, \tag{2}$$

and if the postshock gas mixes then with the rest of baryons instantaneously (on times shorter than recombination time), the average fractional ionization is

$$x \simeq \frac{6 T_v e^{-15.78\delta/T_{v4}}}{1 + 6\delta^{-1} T_v e^{-15.78\delta/T_{v4}}}. \tag{3}$$

In fact, for a massive enough clump processed by a shock the dynamical time τ_d can be larger than the relevant ionization and chemical times, and the postshock gas recombines and initiates molecules to form, resulting in a substantial enrichment of halos with H_2 and HD. This possibility is discussed in [2].

3 RESULTS

Following the ideology described in [1] we compute then the minimal masses of the first objects versus redshift for a set of δ (Fig. 1). The decrease in δ corresponds to an increase in postshock temperature, and the respective increase of fractional ionization. Subsequent mixing of electrons with the surrounding gas enhances H_2 formation, and results in smaller minimal masses. However, for smallest δ the effect saturates because the amount of electrons brought into the systems by the shocks equals δ. It is seen that the value of minimal mass is systematically lower than obtained in [1] by factor of 3–30 for $\delta = 0.06$, so that at $z = 30$ baryonic objects with $M_b = 10^4 M_\odot$ can have formed. As a consequence, the total amount of baryons converted into luminous objects may have increased, essentially changing, for a top heavy IMF, the reionization history.

4 DISCUSSION

Violent relaxation normally assumed as a mechanism which brings dark matter halos in a virial state, goes through generation of strong fluctuations of gravitational potential and the corresponding velocity field in baryons. The shock waves formed in intersections of the fluctuating hydrodynamic flows heat then baryons to the virial level. As soon as the rates of ionization and chemical processes are nonlinear functions of temperature, the final average (mixed) state of the virialized system can be quite different from the one where

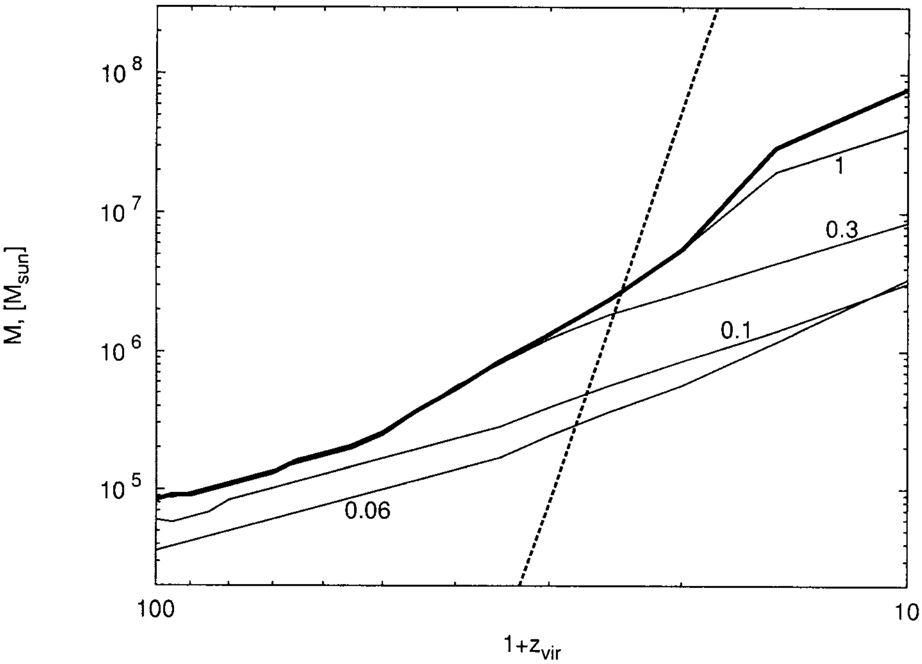

FIGURE 1 The minimal mass of collapsing halos versus virialization red-shift. Only masses above the corresponding curve can form luminous objects: solid lines correspond to different values of $\delta = 0.06$, 0.1, 0.3, 1 from the bottom to the top curves; the upper (thick solid) line reproduces the results of [1]. The dotted curve outlines 3σ peaks in standard CDM ($\Omega = 1$, $\Omega_b = 0.06$, $h = 0.5$), normalized to $\sigma_8 = 0.7$.

the virial state is simply identified by the virial temperature. This means that the dynamical processes associated with the virialization itself may play a crucial role in determining physical parameters of the system in its final virial state. It is quite possible that these processes determine (or at least, affect) the initial mass function of fist stars which can form in shocked gas, the cooled fraction of baryons, the initial star formation efficiency. In particular, in this contribution we have illustrated that the fluctuations of temperature and fractional ionization during the virialization can substantially diminish the minimal mass of first luminous objects.

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References

[1] Tegmark, M., Silk, J., Rees, M.J., Blanchard, A., Abel, T. and Palla, F. (1997). *ApJ*, **474**, 1.
[2] Vasil'ev, E. O. and Shchekinov, Yu. A. (2002). *Astr. Rept.*, submitted.