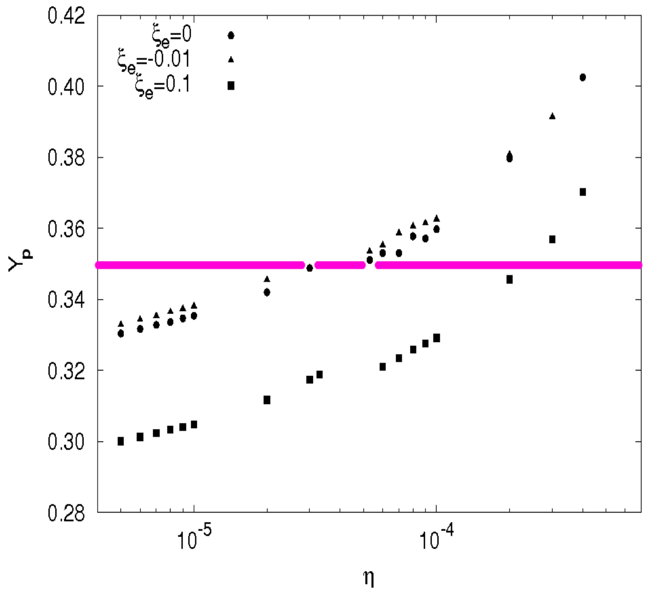

Fig. 1: Results of $Y_{\rm p}$ for some sets of η and ξ_e. The horizontal line at the middle represents $Y_{\rm p} = 0.35$.

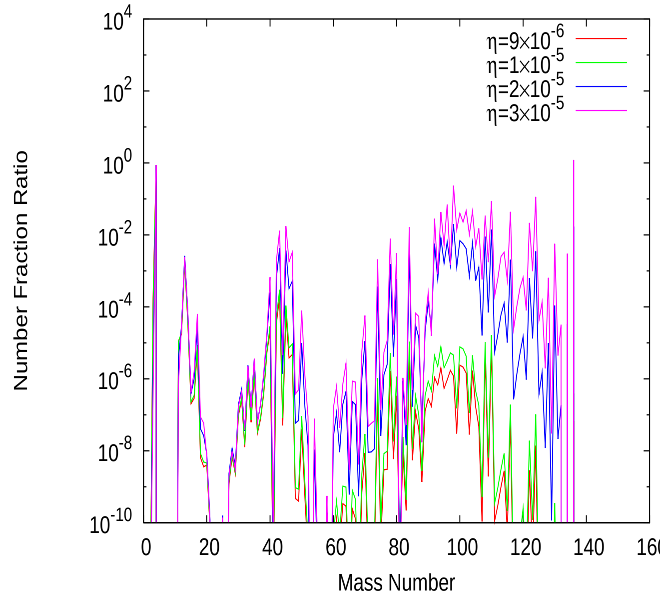

Fig. 2: The number fractions of the produced elements relative to the solar abundances. All the calculations are done with $\xi_e = 0$.

there is a considerable jump in the amount of heavy elements with $A \sim 100$. Fig. 7 of Matsuura et al. [23] shows that $\eta = 10^{-4}$ yields a significant amount of heavy elements with $A \sim 150$, comparable to the solar abundances. With higher η, the abundances of heavy elements continue to increase. Observations show that the amounts of heavy elements are at least a factor of a few less than the solar abundances in the relevant GC [31]. Therefore the upper limit of η is somewhere between 3×10^{-5} and 10^{-4}.

In Fig. 2, some elements $A \sim 100$ are very close to the expected abundances of the GC stars. Thus, it is a good touchstone of our model to check the abundances of the elements $A \sim 100$ in the dwarfs in bMS.

IV. EVOLUTION OF HELIUM ENHANCED REGION

Even if a primordial gas with high $Y_{\rm p}$ was once formed at the time of BBN, it might be mixed with other gases in the outer regions and end up with a lower fraction of helium. We briefly show that the effect of such mixing would not affect the region with high helium abundance. Here, we do not only consider effects of diffusion and accretion, but also take into account self-gravity as a competing process.

A. Diffusion

Helium ions in the region with a higher $Y_{\rm p}$ might diffuse outward the surrounding region with lower helium contents. This effect takes place after the horizon scale exceeds the size of the region, that is, after the temperature becomes lower than $10^8 - 10^7$ K. The diffusion equation for helium is written as

$$\frac{\partial n_{\rm He}}{\partial t} = D \nabla^2 n_{\rm He}, \tag{5}$$

where $n_{\rm He}$ is the number density of helium and D is the diffusion coefficient of helium with electrons and its magnitude is estimated as

$$D = \frac{\lambda v}{3}, \tag{6}$$

where λ is the mean free path of helium ions and $v = \sqrt{3k_{\rm B}T/4m_{\rm H}}$ is the thermal speed of helium ions. Here the constant $m_{\rm H}$ denotes the mass of hydrogen. The time scale $t_{\rm diff}$ of the diffusion is approximated as

$$\begin{aligned} t_{\rm diff} &= \left| \frac{\partial \ln n_{\rm He}}{\partial t} \right|^{-1} \\ &= \left| D \frac{\nabla^2 n_{\rm He}}{n_{\rm He}} \right|^{-1} \\ &\sim \frac{R^2}{D}, \end{aligned} \tag{7}$$

where R is the size of the region.