FORMATION OF POPULATION III OBJECTS DUE TO COSMIC STRINGS

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ABSTRACT. Behind the moving cosmic strings, wakes are formed from dark matter and baryon matter. The shock waves for baryon matter appear after the stage $z \simeq 790(\mu/10^{-6})$. These wakes will fragment into lumps of mass $M \simeq 10^8(\mu/10^{-6})^3(v_{st}/c)^3/(1+z)^{1.5} M_\odot$ where μ and $v_{st} \sim c$ are the line density in units of G=c=1 and the velocity of the strings .

1 INTRODUCTION

It has been discussed that the galaxies are formed by closed cosmic strings (Vilenkin 1985), while not yet so much attention has been paid to the formation of galaxies and other objects in the wakes behind moving cosmic strings, originally suggested by Silk and Vilenkin(1984).

Behind the moving string, the particles obtain the velocity, perpendicular to the direction of the string, as

$$v_t = 4\pi G\mu v_{st}/c^2 = 3.8\times 10^5(\mu/10^{-6})\cdot(v_{st}/c) \text{ cm/sec} .$$

The stage at $v_t = v_s$ where v_s is the sound velocity is given by $1+z_s \simeq 790(\mu/10^{-6})$. Before this stage, the compression of baryon matter propagates with velocity v_s as sound wave into the surrounding space. After $1+z_s$, shock waves will appear behind the string. The temperature behind the strong adiabatic shock is $T \simeq 3m_h \cdot \mu_m v_t^2/(16k_B) \simeq 400(\mu/10^{-6})^2$ K , which is not high enough to ionize the baryon matter, so the cooling is mainly due to H_2 molecules which becomes efficient after $z \simeq 10^2$. The fragmented gas clouds will contract and stars of mass $10^{-1} \sim 10^2 M_\odot$ will be formed (Palla et al. 1983).

2 WAKES OF DARK MATTER AND BARYON MATTER

Assuming that the wake is extending plane-like in the y-z plane infinitely, the equation of motion for dark matter (P=0) and baryon matter is given by

$$d^2x/dt^2 = -4\pi G\rho_b x/3 - 4\pi G\int(\rho-\rho_b)dx - 1/\rho_n \cdot dP/dx ,$$

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where ρ, ρ_b and ρ_n are the total, background and baryon density, respectively. An example of the numerical calculations for $\Omega_d=0.9$ and $\Omega_b=0.1$ started from $1+z_i=10^2$ is given in Figure 1. Dark matter is calculated with 2000 particles for $x\geqq 0$ region and baryon matter is

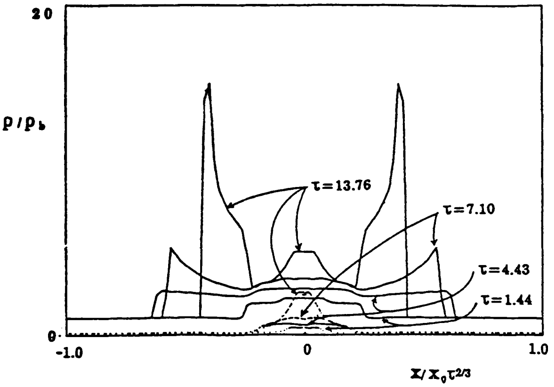

Fig. 1 The density of total matter including the dark and baryon matter. The dotted lines show the density of the baryon matter. The time is normalized as $\tau=t/ti$ where t_i is the initial time. The abscissa is the distance from the symmetric plane, normalized by $x_0\tau^{2/3}$ where $x_0=2v_t/(3t_i)$. The ordinate is normalized by the background density ρ_b.

followed by 500 Lagrangean points.

For the dark matter, infinite density planes appear after the time $\tau\simeq 9$ and they are unstable for fragmentation with the time scale proportional to $\sqrt{\rho_b/\rho}\,t_i\tau$. For baryon matter, the density is much less than that of the dark matter at first, and hence the pressure is almost constant through the layer. After $\tau\geqq 10$, the density increases by its self gravity and the gas pressure gradients appear. The gravitational instability may also occur in the central plane. The fragmented mass could be approximately estimated from the virial mass as

$$M\simeq v_t^2\Delta x/G\simeq 10^8(\mu/10^{-6})^3(v_{st}/c)^3/(1+z)^{1.5}\tau_f^{2/3}(\Delta x/(\tau_f^{2/3}x_0))\ M_\odot\ ,$$

where τ_f is the fragmentation time. The criterions $k^2c^2\leqq 4\pi G\rho$ and including the expanding effects give almost the same mass scale. Even after the fragmentation, dark clouds will oscillate through the central plane.

3 EFFECTS OF POPULATION III OBJECTS

Even though the width of the perturbed region $v_t t$ is small compared to the horizon ct, the energy supply from such Population III objects by shock waves or x-rays from the supernovae or disks around black holes will affect the surrounding space profoundly and other astronomical objects such as galaxies will be formed there (Ikeuchi 1981).

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