On the Evolution of Lyman α Clouds Based upon the Minihalo Model

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Izumi MURAKAMI and Satoru IKEUCHI

Division of Theoretical Astrophysics, National Astronomical Observatory, Mitaka, Tokyo 181, Japan

ABSTRACT We consider intergalactic clouds confined by the gravity of cold dark matter (CDM), the so called minihalo. Assuming a simplified evolution law of UV flux and mass function of gas clouds, we can reproduce number density evolution and HI column density distribution by minihalo model. Considering interaction between supersonic flow and a minihalo, we can investigate no spatial correlation and the proximity effect of Ly α forest.

1. Introduction

Absorption line systems of QSOs prove the physical states at the high redshift universe which is hard to observe directly. Several observational properties are indicated for absorption systems of QSOs[1,2,3,4]. Minihalo model for Lyman α forest is proposed from CDM cosmogony[5,6,7]. In this model, a gas cloud is confined by the gravity of CDM and we calculate cloud evolution to reproduce observational properties of Ly α forest.

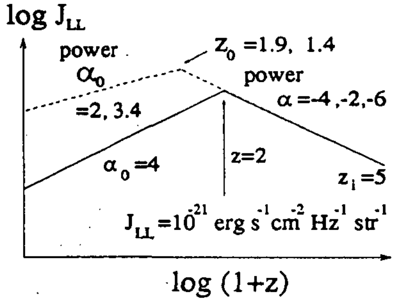

Fig.1 Assumed evolution of diffuse UV flux at Ly limit as a power-law function of $1+z$ with powers α and α_0.

2. Evolution caused by diffuse UV flux

We calculate the evolution of a spherical gas cloud, with primordial abundance, irradiated by the diffuse UV flux. we take into account heating by UV radiation and radiative cooling, and keep the CDM potential unchanged. Initially gas and CDM are in a gravitational equilibrium. We calculate ionization equilibrium. We assume the diffuse UV flux as $J_\nu(r;z) = J_{LL}(z)(\nu/\nu_{LL})^{-1}\exp(-\int_r^R n_{HI}dr/10^{17.5}\mathrm{cm}^{-2})$, and the evolution of $J_{LL}(z)$ at Ly limit, ν_{LL}, as Fig. 1. Here we take $\Omega = 1$, $q_0 = 0.5$, and $H_0 = 100\mathrm{km\ s^{-1}Mpc^{-1}}$. Parameters which characterize minihalos are: $D = \rho_d(r=0)/\rho_{crit}(z=10)$, and $X = \sigma_d^2/c_s^2(10^4\ \mathrm{K})$, where $\rho_{crit}(z)$ is the critical density at the epoch z, σ_d is the velocity dispersion of CDM, and $c_s(T)$ is the sound speed of gas.

We calculate HI column density as a function of an impact parameter, p. Setting comoving space density of minihalos to be constant with a power law mass function, we take 'observed' number as

$$\frac{d^2\tilde{\mathcal{N}}}{dzdN_{HI}} = \frac{c\pi}{H_0}n_*(0)\int\left(\frac{M_c}{M_*}\right)^{-\delta} d\left(\frac{M_c}{M_*}\right)\left|\frac{pdp}{dN_{HI}}\right|(1+z)^{1-q_0}. \quad (1)$$

This equation is valid only for $q_0 = 0$ or 0.5. In order to compare with observation, we calculate the z-integrated column density distribution averaged by absorption distance[1,8]. The number density evolution are obtained by integrating Eq.(1) with the column density[2,3]. We assume the continuum depression D_A comes from cumulative absorption of clouds[9].

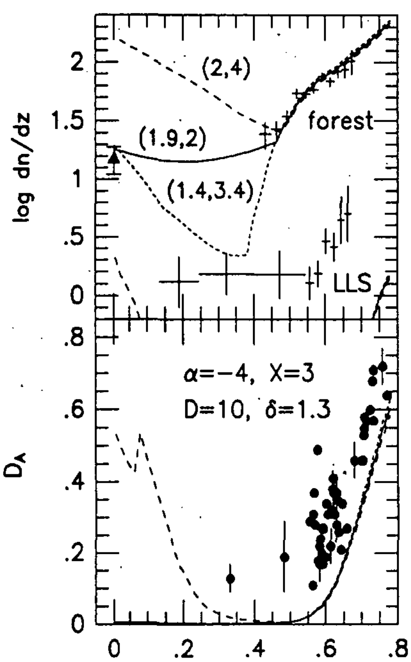

Fig.2 Number density evolution (upper panel) and continuum depression (lower) where lines are calculated results with (z_0, α_0). Crosses[2,3], triangle[4], and dots[9] are of ovserbations.

For $\alpha > 0$ clouds gradually contract and neutral fraction of hydrogen increase due to the decrease of UV flux. When n_{HI}/n_H approaches unity at the center of cloud, the HI region, called neutral core, appears and grows up to be unstable and collapse. For $\alpha < 0$ clouds expand slowly. Since cross section for fixed HI column density becomes smaller with decreasing flux, observed number density and continuum depression decrease (Fig.2). HI column density distribution can be roughly approximated to a power-law form and fits observed one well.

Best fit model of UV flux is $\alpha = -4$ at $z \geq 1.9$ and $\alpha_0 = 2$ at $z \leq 1.9$ ($z_0 = 1.9$). Prefered values of other parameters to explain observations are: $\delta = 0.9 \sim 1.6$, $X \gtrsim 1$, and $D \sim 10$.

We propose a unified picture for HI absorption systems in this model. We can regard the Ly α forest as less massive ionized clouds and/or ionized envelopes of clouds with neutral cores, and high HI column density systems as neutral cores of massive clouds. Number of high column density components is smaller than observed one because the present model is restricted in the mass range of clouds. We must include massive collapsed systems and we may regard them as non-evolving components of LLSs. In our expanding minihalo model, gas clouds collapse at $z < 1$. These late collapse corresponds to formation of young dwarf galaxies[10].

3. Evolution caused by supersonic flow

We calculate the evolution of an initially spherical gas cloud exposed to supersonic gas flow in order to investigate the proximity effect and no spatial correlation for Ly α forest. Such flow seems to occur when a minihalo moves against ambient matter or a blast wave propagates from a QSO[11].

The gas cloud, of which central pressure is lower than the ram pressure of a supersonic flow, is blown out from the potential of minihalo. On the other hand, the gas cloud, of which central pressure is higher than the ram pressure, is stripped gradually by bow shock, if the escape velocity of gas is smaller than the velocity of gas flow. The timescale of this strip depends on the distribution of dark matter and the density and velocity of gas flow.

For the proximity effect, if we consider the blast wave ejected from a QSO with energy larger than 10^{63} erg, clouds are blown off from the potential of dark halos within $2 \sim 3$ Mpc from a QSO, which is its propagating distance by $z \sim 2$.

We consider the clustering of minihalos, which naturally occurs in the CDM cosmogony. In such a process, minihalos gain random velocity, which is about the virial velocity of the cluster, relative to surrounding matter. The moving gas clouds feel the ram pressure and are stripped. If we take mass and radius of such a cluster as ones of galaxies, the gas clouds can be stripped via their motion in a dense cluster and not be seen with time scale shorter than the Hubble time (Fig.3). As a result, the gas clouds which show high spatial correlation cannot be observed as absorption lines because their gas is almost stripped.

The minihalo model based on the CDM cosmogony can represent many characteristic properties of Lyman α forest and this result becomes one of indirect evidences supporting CDM scenario for the galaxy formation.

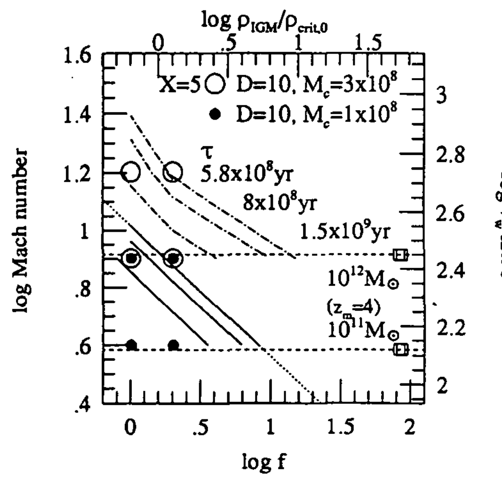

Fig.3 Contours of time scale losing gas for two clouds in flow density and velocity space. Squares are for clusters of minihalos.

References

1. W.L.W.Sargent, C.C.Steidel, and A.Boksenberg 1989, *Ap.J. Suppl.* **69**, 703.
2. L.Lu, A.M.Wolfe, and D.A.Turnshek, 1991, *Ap.J.*, **367**, 19.
3. K.M.Lanzetta 1991, *Ap.J.* **375**, 1.
4. J.N.Bahcall *et al.*, 1992, preprint.
5. M.J.Rees 1986, *M.N.R.A.S.* **218**, 25p.
6. S.Ikeuchi 1986, *Ap. Space Sci.* **118**, 509.
7. S.Ikeuchi, I.Murakami, and M.J.Rees 1988, *M.N.R.A.S.* **236**, 21p
8. D.Tytler 1987, *Ap.J.* **321**, 69.
9. D.P.Schneider, M.Schmidt, and J.E.Gunn 1989, *A.J.* **98**, 1951.
10. I.Murakami and S.Ikeuchi, 1991, submitted to *Ap.J.*
11. I.Murakami and S.Ikeuchi, 1992, in preparation.