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Ionization States of Metallic Absorption-Line Systems in Continua of Quasars

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ABSTRACT We study ionization states of metallic absorption - line systems in continua of quasars (QSOs), assuming that the metallic lines arise in gaseous halos of high-redshift galaxies in photoionization equilibrium under the background UV radiation, and obtain constraints on the intensity and spectral shape of the UV radiation. Then we discuss a structure of absorbers suitable for all of the metallic absorption - line systems.

1. INTRODUCTION

Metallic absorption - line systems in QSO spectra are generally supposed to be in photoionization equilibrium under the diffuse UV background, whose existence is supported by the Gunn-Peterson test (e.g., Gunn & Peterson 1965). These absorption systems can be classified into three groups, i.e., CIV system, Lyman limit system (LLS) and MgII system, according to the ionization state, in other words according to the column density of neutral hydrogen. However, we can study the ionization states of metallic absorption systems on the hypothesis that these difference in ionization states of three kinds of the absorption systems is caused by the difference in lines of sight through the absorbing halos. For example, Lanzetta, Turnshek & Wolfe(1987) suggested that MgII - absorbing clouds and CIV - absorbing clouds are grouped together and that the MgII clouds are concentrated toward the center of the group, on the other hand, the CIV clouds toward the edge. Furthermore, it is clear from observations at high spectral resolution that the metallic absorption - line systems consist of several subcomponents (e.g., Blades 1988). Their Doppler parameters are typically $b = 5 - 15$km s^{-1} and the total velocity spread of subcomponents ranges from ~ 50km s^{-1} to ~ 800km s^{-1}. There have been a few analyses on the clumpy structure of absorbers (e.g., Lanzetta & Bowen 1990). Lanzetta & Bowen (1990) found that a radial profile of the spatial density of the clump roughly proportional to $r^{-\beta}$, with $\beta \simeq 2-3$.

In this paper, first, we assume a very simple model - absorber which has a density distribution $n_H \propto r^{-2}$ and examine probable contributions to ionizing radiation 1) from QSOs ; I_ν^d and/or 2) from early-type stars in the central high-z galaxy ; I_ν^s. Then we find constraints on the UV radiation to repoduce the observed ionization states of the metallic absorption-line systems. Second, we consider clumpy model - absorbers irradiated by the UV radiation obtained here and discuss a structure of these absorption - line systems.

2. Calculation

We calculate the ionization states of model - absorber under the conditions of photoionization equilibrium and thermal equilibrium. We assume an intensity of ionizing radiation including a correction for self-absorption due to halo gas: $I(\nu;r) = I_{\nu_{LL}}^d(\nu/\nu_{LL})^{-\alpha}\exp(-\tau_O) + I_\nu^s/(r/r_0)^2\exp(-\tau_I)$, where $\tau_O = \int_r^R n_{HI}dr/10^{17.5}\text{cm}^{-2}$, $\tau_I = \int_{r_0}^r n_{HI}dr/10^{17.5}\text{cm}^{-2}$ (R : radius of absorber, r_0 : inner radius). I_ν^s is adopted from Bregman & Harrington (1986) with upper cut-off at 500eV.

In order to compare with observations (summarized in Table 1 of Bergeron & Stasińska 1986), we calculate HI column density and column densities of several ions, e.g., CIV, MgII and SiIV. When we consider a clumpy model, we assume that an absorber consists of two components, with spatial density n^1 and n^2, respectively. The filling factor of subcomponent 2; $f(r) \equiv \Sigma V_{clump}/V_{total}$ is used to modify the column density of each ion on a line of sight at an impact parameter p, $N_{xi} = 2\int_p^R(n_{xi}^1(r)(1-f(r)) + n_{xi}^2(r)f(r))r/\sqrt{r^2-p^2}dr$. The optical depth is also modified according to the modification of N_{HI}. But for simplicity, we assume that $f(r)$ is constant in this paper. The chemical elements considered in our calculations are H, He, C, N, O, Mg, Si and Fe. We adopt the solar abundance from Allen (1972) and assume the metallicity of absorbing halos to be $Z/Z_\odot = 10^{-2}$.

3. Results and Discussions

In order to reproduce the observed ionization states, we find that the hydrogen Lyman - limit intensity of the diffuse UV background should be $\log I_{\nu_{LL}}$(in ergs $cm^{-2}s^{-1}Hz^{-1}str^{-1}$) $= -21.0 \pm 0.5$ at $z \sim 2$ and its spectral shape should be $I_\nu \propto \nu^{-\alpha}$ with spectral index $1.5 \lesssim \alpha \leq 2$. It appears that quasars would be the dominant source of UV radiation at high redshifts and that the contributions from young galaxies should be negligible (See Figure 1 and Denda & Ikeuchi 1992). This result is consistent with previous studies (e.g., Steidel and Sargent 1989).

However, it is difficult to reproduce the observed ionization states of all of the three absorption systems at once, when we assume a spherical symmetric absorber with density distribution $n_H \propto r^{-2}$. Then we consider the cases of two - component models. The observed ionization states of all kinds of the metallic absorption systems are well reproduced by the clumpy model that has a smoothly distributed and thicker region, where $n_H \propto r^{-2}; r \lesssim 10$kpc, and a thin outer region with 'clumps', where a filling factor of 'clumps' is about 0.1 (See Figure 2). Moreover, the absorber may have an inner dense core which shields its gaseous halos from the stellar UV radiation of the central high-z (young) galaxy.

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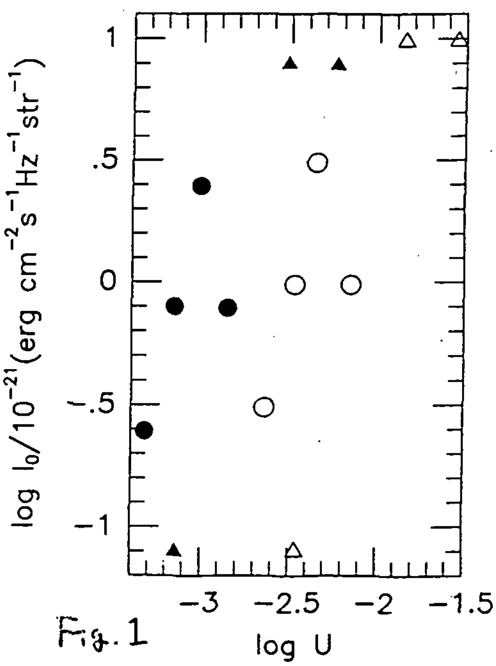

Fig. 1

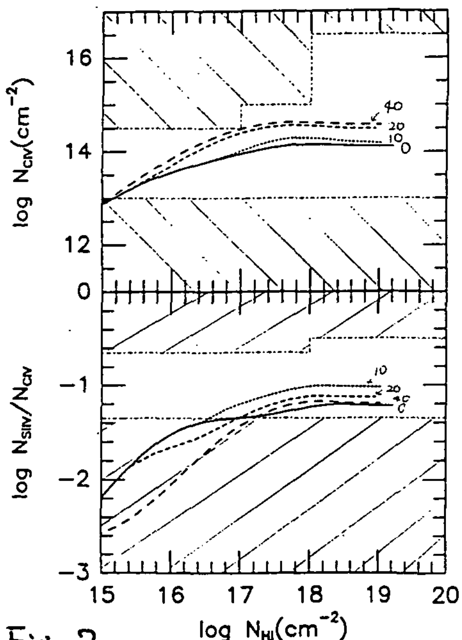

Fig. 2

Fig. 1 : $\log I_{\nu_{LL}}$ versus $\log U$ for the suitable models to observations. The UV flux with spectral index $\alpha = 2$ is adopted here. Open circles and closed circles represent values, for which both the observations of the CIV systems and that of LLS can be well reproduced, respectively. Open triangles and closed triangles reprsent values, for which the CIV systems or LLS isn't reproduced, respectively. From this figure, it is seen that $\log I_{\nu_{LL}}$(in ergs $cm^{-2}s^{-1}Hz^{-1}str^{-1}$) $= -21 \pm 0.5$ and $\log U = -2.75 \pm 0.75$ are suitable for the ionization states of both the CIV systems and LLS.

Fig. 2 : The upper panel is the column density of CIV ion, N(CIV), versus the neutral hydrogen column density, N(HI), and the lower one is the ratio of column densities N(SiIV)/ N(CIV) versus N(HI) for clumpy models for (n_H^1, n_H^2, f, n_H^c)= (0.1, 1.0, 0.1, 1.0), with different size of snoothly distributed region ; r_c and UV radiation with a spectral index $\alpha = 2$ and intensity $\log I_{\nu_{LL}}$(in ergs $cm^{-2}s^{-1}Hz^{-1}str^{-1}$) = -21. The values of r_c is labeled on each curve and the hatched regions are excluded by the observational limits.