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A COMPARISON OF METAL AND LY-α ABSORPTION IN GALACTIC HALOES

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SUMMARY: The metallicity structure of galactic haloes is one of the major unknowns in modern galactic astrophysics and observational cosmology. Hereby we outline a very simple method for obtaining at least a crude picture of gas abundances, based on recent important statistical determination of the relationship between neutral hydrogen absorbing column density and galaxy impact parameter. It is a fine illustration of the great theoretical and observational power of low-redshift Lyα absorption studies. Future detailed analyses of large samples of absorption- selected galaxies will certainly provide us with more data on the abundance structure of extended gaseous component of galaxies.

1. INTRODUCTION

Great progress has been made during the last few years in deepening our understanding of the QSO absorption line systems at both early and recent epochs. One of the most significant discoveries is the observational confirmation of a brilliant early idea of Bahcall and Spitzer (1969) that most (if not all) of low-redshift absorption lines seen in spectra of all known QSOs arise in very extended gaseous envelopes of ordinary galaxies (Bregman 1981; Lanzetta and Bowen 1992; Lanzetta *et al.* 1995; Bowen *et al.* 1996; Chen *et al.* 1998). For the subset of metal lines, that was known for about a decade (e.g. Sargent *et al.* 1988; Yanny 1992), but only with coincidence analysis for Lyα systems which dominate any sample of QSO absorbers, we may hope to achieve a unified view of gaseous absorbing haloes of normal galaxies as a generic phenomena.

In view of recent establishment of quantitative statistical relations pertaining to the column density of neutral hydrogen in low-redshift galactic haloes, it is of some interest to compare these data with those obtained for metal-line absorbers in the same redshift range, and under the hypothesis that they are members of the same parent population of absorbing clouds associated with luminous galaxies, both being generic products of the process of hierarchical structure formation in the universe (e.g. Mo and Miralda-Escudé 1996).

Our goal in the rest of this paper is, therefore, to outline the connection of observed column densities of metal line absorbers, specifically a high-ionization species like C IV, with underlying distribution of neutral hydrogen column densities. The crucial role of the metallicity of halo gas for solving of this problem is obvious. A similar discussion was given in Petitjean and Bergeron (1994), but without taking into account the crucial Lyα column density analysis. The procedure is outlined on the example of C IV ion, but is entirely applicable to other metal species encountered in the absorbing gas. Apart from its established presence in the Lyα forest (Lu 1991; Cowie *et al.* 1995; Fernández-Soto *et al.* 1996), carbon absorption is chosen because successful determination of its correlation with impact parameters of low-redshift associated galaxies would most effectively disprove "different population" theories on the origin of QSO absorption line systems (e.g. Peng and Weisheit 1991). It should be emphasized that this analysis applies, of course, only to a subset of metal absorption lines truly arising in haloes of normal galaxies, and not in any other cosmological objects (e.g. gas in rich clusters, or galactic winds from starbursts).

2. CARBON ABSORPTION IN LOW REDSHIFT HALOES

The equivalent width of C IV absorption line at 1548.20 Å (in laboratory reference frame or at low redshift) in linear regime may be written as (e.g. Srianand and Khare 1993, 1994)

$$W(1548.20) = 4.1 \times 10^{-2} \left(\frac{N_{\rm C\,IV}}{10^{13}\ {\rm cm}^{-2}} \right) \text{Å}. \quad (1)$$

The carbon column density $N_{\rm C\,IV}$ is connected with the neutral hydrogen column density through the simple relation which includes uniform (or averaged) metallicity

$$N_{\rm C\,IV} = 3 \times 10^{13} \left(\frac{N_{\rm H\,I}}{10^{18}\ {\rm cm}^{-2}} \right) f_{\rm C\,IV} \frac{Z}{0.1 Z_\odot}\ {\rm cm}^{-2}, \quad (2)$$

where Z is the metallicity of the absorbing gas, and C IV fraction is defined as

$$f_{\rm C\,IV} = \frac{n_{\rm C\,IV}}{n_{\rm C}}, \quad (3)$$

$n_{\rm C}$ being the total carbon number density in all ionization states.

From the work of Chen *et al.* (1998), we have learnt the relation between Lyα absorbing column density and absorbing galaxy impact parameter in form

$$N_{\rm H\,I} = 10^{\xi} \left(\frac{\rho}{10\ {\rm kpc}} \right)^{-\gamma} \times 10^{21}\ {\rm cm}^{-2}, \quad (4)$$

where the best-fit values for constants ξ and γ are $\xi = 1.09 \pm 0.90$ and $\gamma = 5.33 \pm 0.50$.

The Eq.(2) applies literally only to a homogeneous medium. If we consider a spherical halo of the radius R_0 intercepting a line-of-sight toward a QSO, we shall effectively see the values of carbon fraction and metallicity averaged over the column of gas along the line-of-sight. In assumption of spherical symmetry of the distribution of any physical quantity $\kappa(r)$, its mean value along the line-of-sight at impact parameter $\rho < R_0$ is, from the purely geometrical considerations,

$$\langle \kappa \rangle_\rho = \frac{1}{\sqrt{R_0^2 - \rho^2}} \int_\rho^{R_0} \frac{r \kappa(r) dr}{\sqrt{r^2 - \rho^2}}. \quad (5)$$

On the other hand, from the equations (1) and (2) we obtain

$$\langle f_{\rm C\,IV} Z \rangle_\rho = 6.61 \times 10^{-5} W \left(\frac{\rho}{10\ {\rm kpc}} \right)^{5.33} Z_\odot, \quad (6)$$

where the equivalent width W is given in Å , and the best-fit values of Chen *et al.* (1998) are used.

Plausible assumptions need to be made about the C IV fraction. For $f_{\rm C\,IV} \approx 1$ we obtain the lower limit of $\langle Z \rangle_\rho$. Still, it is well known that temperatures in the metal line absorbers are much lower than $T = 3 \times 10^5$ K, at which carbon is mostly in C^{+3} form, and the metagalactic ionizing background does not possess enough photons at energies higher than 54.4 eV. The realistic photoionization models give values close to (Petitjean *et al.* 1992; Petitjean and Bergeron 1994)

$$f_{\rm C\,IV} = 0.4. \quad (7)$$

We shall use this fiducial value in further discussion, although in subsequent more detailed modelling it is necessary to employ a variant of the Eq. (5), taking into account the radial dependence of the ionization structure.

Thus, for a given metallicity profile, we should be able, from the Eqs. (1), (2) and (5), to predict equivalent width of a C IV absorption line arising in halo of a galaxy observed at a given impact parameter smaller than R_0:

$$\log W(\rho) = 3.782 + \log \left(\frac{1}{\sqrt{R_0^2 - \rho^2}} \int_\rho^{R_0} \frac{r Z(r) dr}{\sqrt{r^2 - \rho^2}} \right) - 5.33 \log \left(\frac{\rho}{10\ {\rm kpc}} \right). \quad (8)$$

3. DISCUSSION OF THE EXPONENTIAL PROFILE

For example, we can adopt an exponential metallicity profile, similar to that adopted by Srianand and Khare (1993, 1994):

$$Z(r) = Z_0 \exp \left(- \frac{r}{r_0} \right), \quad (9)$$

(Z_0 and r_0 are constants normalized, say, on Milky Way abundance observations) and try to predict observed equivalent widths for a given value of impact parameter, in order to compare with C IV absorbers found in the literature (Sargent *et al.* 1988; Lanzetta *et al.* 1995).

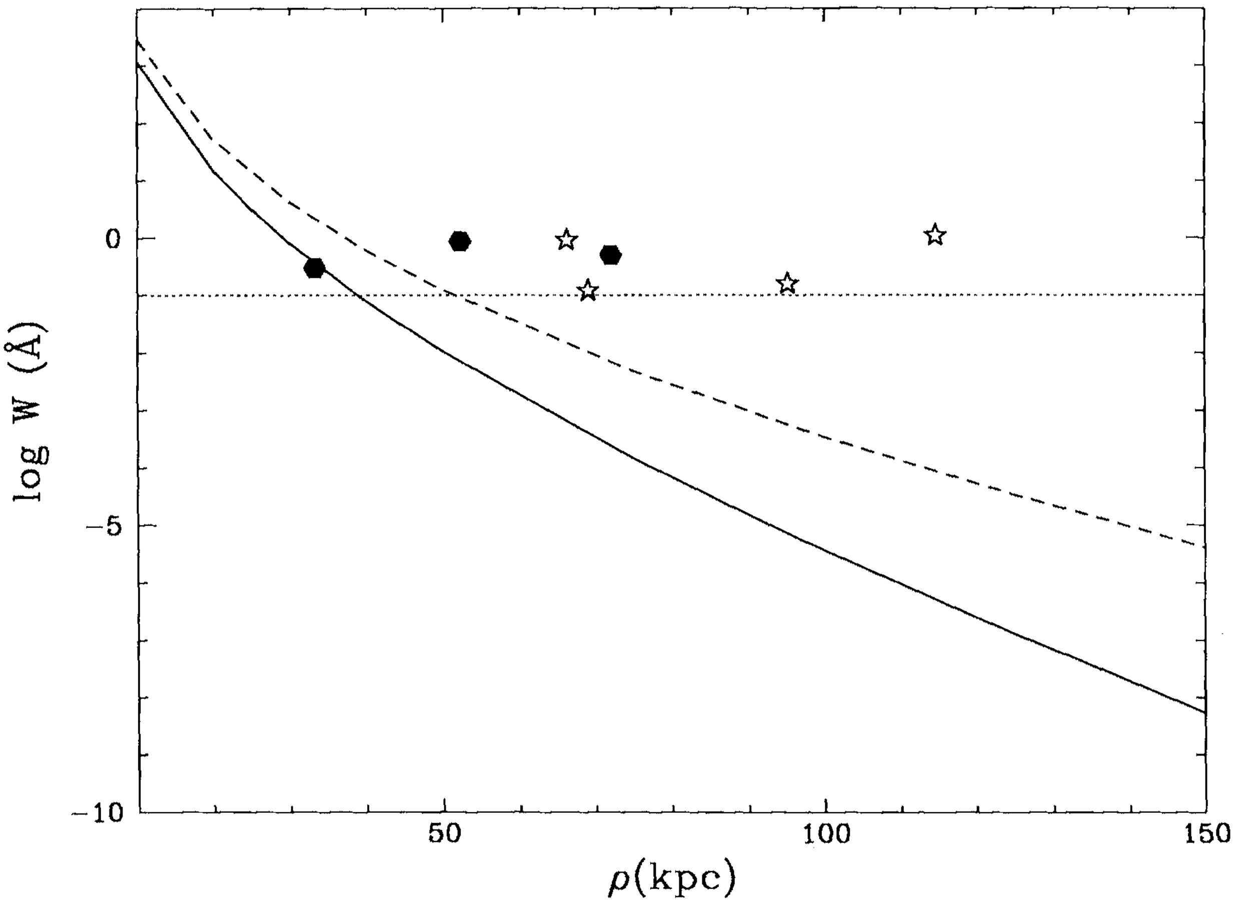

Fig. 1. *Predicted C IV equivalent widths (W(Å)) for the metal absorbers belonging to the same population as low-redshift Lyα halo absorption systems, and exponential metallicity profile (see text). ρ is the impact parameter.*

These results are shown in the Fig. 1. Maximal radius of galaxies for Lyα absorption is taken from Chen *et al.* (1998), and value $h = 0.5$ is used throughout. Parameters of the metallicity distribution are $Z_0 = 1.0\ Z_\odot$ and $r_0 = 10.87$ kpc (solid line), and $Z_0 = 1.0\ Z_\odot$ and $r_0 = 20$ kpc (dashed line). The horizontal dotted line denotes observational threshold for equivalent width of 0.1 Å. The observational points are taken from Bahcall *et al.* (1992), Lanzetta *et al.* (1995) and Lanzetta *et al.* (1996). Filled points denote detected C IV absorption, and starred points are *upper limits* in cases with no absorption detected. One should keep in mind that sizes (i.e. luminosities) of galaxies are often not quoted, and may be significantly different from the canonic case of an L_* galaxy. Where they are quoted, the points which were chosen correspond as closely as possible to that case. This shows the most serious problem we are likely to encounter in attempts to test metallicity models in this manner: namely, bias towards strong carbon absorbers is going to significantly skew the results in any reasonably incomplete sample. Whether strong absorption arises from the tails of metallicity distribution, or those are simply huge galaxies for which the L_* model is not applicable, we are not currently in position to judge, since existing sparse coincidence statistics are rarely quoting information on the luminosity of absorbing galaxy. For this reason, we expect to see all observational point more or less above the theoretical equivalent width profile derived in the Eq. (8). We shall have to wait until the development of observational techniques enables the decrease in the detection threshold for another order of magnitude, and more extensive absorber-galaxy coincidence samples offer us a better chance of discriminating among various metallicity models.

We notice that the threshold impact parameter for $r_0 \sim 10$ kpc is ~ 40 kpc, intriguingly similar to the median impact parameter of C IV absorbing galaxies in Aragón-Salamanca *et al.* (1994) sample (at redshift $z > 1$, however) and typical sizes of Mg II absorbers (e.g. Bergeron and Boissé 1991). Still, it seems that a single exponential profile is quite poor fit to (unfortunately very sparse) data available. Probably a combination with exponential decline in the inner parts of the halo, and constant or slowly declining metallicity in the outer parts would be able to achieve significantly better results.

4. CONCLUSIONS

We have sketched a plausible way to improve our very insufficient knowledge on the metallicity of gas in galactic haloes. It clearly shows great cognitive power of the low-redshift Lyα analysis. One of the important obstacles to this method is, of course, the impossibility to observe C IV lines from the ground at low redshift, so that we still do not have a satisfactory sample of carbon absorption-selected galaxies at $z < 1$. But, considering the explosive growth of space-based astronomy in recent years, this difficulty is likely to be overcome in very near future.

If we establish the metallicity behavior with sufficient confidence, the Eq. (6) may serve for constraining the ionization variations within halo of a particular galaxy, since the offset of observed equivalent width from the predicted one will be probably due to spatial variations in $f_{\rm CIV}$, i.e. in complex ionization structure of absorbing halo clouds. This may be the case especially in the inner parts of the haloes, where internal ionization may likely occur, either through leakage of Lyman limit photons from the disk or sources truly embedded in the halo. Conversely, if existence and properties of the internal ionizing sources are established, we may be able to remove the uncertainty in $f_{\rm CIV}$ (or whatever other metal species we are considering), and so get better hold on, in a sense complementary, metallicity structure.

It is easy to see the way present discussion can be generalized to a case of flattened haloes, made of constant-density nested ellipsoids (e.g. Pitts and Tayler 1997). Also, near the center of the halo, effects of finite optical depth need to be taken into account. These, and other, improvements of the model will, in our hope, encourage the further work on more sophisticated, detailed models of metallicity structure of galactic haloes.

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ПОРЕЂЕЊЕ МЕТАЛНЕ И ЛАЈМАН-АЛФА АПСОРПЦИЈЕ У ГАЛАКТИЧКИМ ХАЛОИМА

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Оригинални научни рад

Металичност у гасним галактичким халоима јесте једна од главних непознаница савремене галактичке астрофизике и космологије. У овом раду се скицира веома једноставан метод за добијање грубе слике о хемијском саставу гаса у халоима, заснован на недавном одређивању везе између линијске густине апсорбујућег неутралног водоника и галактичког параметра судара. То је истовремено и добра илустрација теоријског и посматрачког значаја проучавања Лыα апсорпције на малим црвеним помацима. Будуће детаљне анализе великих узорака галаксија изабраних на основу познате апсорпције, свакако ће нам пружити знатно више података о хемијској структури гасних омотача галаксија на великој скали.