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THE H I MASS DENSITY IN GALACTIC HALOS, WINDS, AND COLD ACCRETION AS TRACED BY Mg II ABSORPTION

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ABSTRACT

It is well established that Mg II quasar absorption lines arise from gas structures associated with galaxies. The degree to which galaxy evolution is driven by the gas cycling through halos is highly uncertain because their gas mass density is poorly constrained. Fitting the Mg II equivalent width (W) distribution with a Schechter function and applying the N(H I)–W correlation of Ménard & Chelouche, we computed $\Omega(\text{H I})_{\text{Mg II}} \equiv \Omega(\text{H I})_{\text{halo}} = 1.41^{+0.75}_{-0.44} \times 10^{-4}$ for $0.4 \leq z \leq 1.4$, excluding H I from DLAs. We deduce the cosmic H I gas mass density fraction in galactic halos traced by Mg II absorption is $\Omega(\text{H I})_{\text{halo}}/\Omega(\text{H I})_{\text{DLA}} \simeq 15\%$, $\Omega(\text{H I})_{\text{halo}}/\Omega(\text{H I})_{\text{tot}} \simeq 13\%$, and $\Omega(\text{H I})_{\text{halo}}/\Omega_b \simeq 0.3\%$. Citing several lines of evidence, we propose infall/accretion material is sampled by small W whereas outflow/winds are sampled by large W, and find $\Omega(\text{H I})_{\text{infall}}$ is consistent with $\Omega(\text{H I})_{\text{outflow}}$ for bifurcation at $W = 1.23^{+0.28}_{-0.15}$ Å; cold accretion would then comprise no more than $\sim 7\%$ of $\Omega(\text{H I})_{\text{tot}}$. We discuss evidence that (1) the total H I mass cycling through halos remains fairly constant with cosmic time and that the accretion sustains the winds, and (2) evolution in the cosmic star formation rate depends primarily on the *rate* at which cool H I gas cycles through halos.

Subject headings: galaxies: halos — galaxies: intergalactic medium — quasars: absorption lines

1. INTRODUCTION

Galaxies are complex ecosystems in which baryonic matter is cyclically transformed between gas and stars. The stochastic mechanisms governing the gas can include accretion from mergers and the intergalactic medium, mixing/recycling of the disk/halo via winds, fountains, and/or chimneys, and expulsion via high velocity winds. Current studies of galaxy evolution rely on both observations and simulations to sharply focus on how galaxies acquire, chemically enrich, recycle, and expel their gaseous component. However, the mean *quantity* of halo gas engaged in any given process over the long history of a galaxy's lifetime remains very poorly constrained.

Gas in galaxies is most sensitively probed with absorption lines, which yield its kinematics, metallicity, density, temperature, and statistical spatial extent. Dense neutral hydrogen gas confined within galaxies commonly exhibits damped Lyα absorption [$N(\text{H I}) \geq 2 \times 10^{20}$ cm^{-2} $\equiv$ DLA]. DLAs are fundamentally different from other classes of absorption systems, for example, the Lyman limit systems [$10^{17.3} < N(\text{H I}) < 10^{20.3}$ cm^{-2} $\equiv$ LLS], for which the hydrogen is partially or substantially ionized (cf., Prochaska 1999) and the statistical spatial extent[5] around galaxies is ~ 100 kpc. DLAs can account for up to $\sim 50\%$ of the galactic baryonic content and are believed to probe the cool, dense precursors of star forming molecular clouds (cf., Wolfe et al. 2005)

Rao et al. (2006) measured the cosmological neutral gas mass density traced by DLAs at a mean redshift of $z = 0.92$ to be $\Omega(\text{H I})_{\text{DLA}} = (9.6 \pm 4.5) \times 10^{-4}$. It has been argued that $\Omega(\text{H I})_{\text{DLA}}$ remains roughly constant for $z \sim 0.2-5$ (Prochaska & Herbert-Fort 2004; Péroux et al. 2005; Rao et al. 2006; Lah et al. 2008; Songaila & Cowie 2010; Meiring et al. 2011) and then decreases by a factor of ~ 6 by $z = 0$ (Zwaan et al. 2005; Martin et al. 2010). However, Noterdaeme et al. (2009) reported a significant decrease of $\Omega(\text{H I})_{\text{DLA}}$ from $z = 4$ to $z = 2.2$ and suggested it continues decreasing for $z < 2.2$. Extrapolation of their H I column density distribution, $n(N)$, below $\log N(\text{H I}) = 20.3$ yields an LLS contribute $\simeq 13\%$ of the total Ω(H I) at $z > 2.2$ (also see Péroux et al. 2005).

Since the global star formation rate (SFR) history of the universe has evolved dramatically (e.g., Madau et al. 1998), if the redshift constancy of $\Omega(\text{H I})_{\text{DLA}}$ holds, it implies that DLA gas does not directly track the formation of stars. This might imply that the global SFR is predominantly governed by mechanisms link to galactic halos, such as gas accretion from the intergalactic medium and/or energetic recycling of gas within galaxies themselves. An estimate of $\Omega(\text{H I})_{\text{halo}}$ (excluding H I from DLAs) as the sum of an accreting/infall component, $\Omega(\text{H I})_{\text{infall}}$, and a wind/outflow component, $\Omega(\text{H I})_{\text{outflow}}$, could place constraints on the relative importance and roles with which these processes drive star formation in galaxies.

The Mg II $\lambda\lambda 2796, 2803$ doublet is a strong absorption line pair employed to study the gaseous components of $z < 1$ galaxies (see Churchill, Kacprzak, & Steidel 2005, for a review). Mg II absorption selects low-ionization gas with $10^{16} \leq N(\text{H I}) \leq 10^{22}$ cm^{-2} (Churchill et al. 2000; Rao & Turnshek 2000; Rigby, Charlton, & Churchill 2002) out to projected galactic radii of ~ 100 kpc (Kacprzak et al. 2008; Chen & Tinker 2008; Chen et al. 2010a). For Mg II absorption restframe equivalent width $W \geq 1$ Å, galaxy color and star formation rate correlates strongly with W (Zibetti et al. 2007; Ménard et al. 2009; Noterdaeme et al. 2010; Nestor et al. 2011), a result highly suggestive that galactic outflows are responsible for ejecting substantial amounts of gas to large galactocentric radii. Chelouche & Bowen (2010) demonstrated that models of outflowing wind-driven gas reproduce the Mg II velocity widths of $W \geq 1$ systems observed with high resolution (Bond et al. 2001; Churchill & Vogt 2001).

Indeed, direct evidence for Mg II absorbing winds is seen in

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[5] LLS have dN/dz consistent with that of Mg II absorbers (Stengler-Larrea et al. 1995; Nestor et al. 2005), which have $R_* \simeq 100$ (Kacprzak et al. 2008; Chen & Tinker 2008; Chen et al. 2010a).

spectra star forming galaxies, which exhibit strong outflows blueshifted 300 – 1000 km s^{-1} relative to the galaxy (Tremonti et al. 2007; Weiner et al. 2009; Martin & Bouché 2009; Rubin et al. 2010a,b). These galaxies almost exclusively exhibit $W \geq 1$ Å absorption. The extent of these winds are not well constrained; however, Bordoloi et al. (2011) suggest that Mg II absorbing winds may reach out to ~ 50 kpc.

For samples dominated by $W < 1$ Å, neither Chen et al. (2010a) nor Kacprzak et al. (2011b) found a W–galaxy color correlation, contrary to the (Zibetti et al. 2007) result for $W > 1$ Å. Furthermore, Chen et al. (2010b) found that Mg II "halo size" increases with increasing galaxy stellar mass and weakly with specific star formation rate, suggesting a scenario in which infalling Mg II absorbing gas structures (selected by $W < 1$ Å absorption) fuel star formation.

The SPH simulations of Stewart et al. (2011a) reveal that gas-rich mergers and cold-flow streams produce a circum-galactic co-rotating, low-ionization gas component that is predominately infalling towards the galaxy. In absorption, these structures are expected to exhibit ~ 100 km s^{-1} velocity offsets relative to the host galaxy, consistent with the observations of Steidel et al. (2002), Kacprzak et al. (2010a), and Kacprzak et al. (2011a). This spatial/kinematic configuration predicts a correlation between galaxy inclination and W, which has been observed by Kacprzak et al. (2011b).

The above body of evidence suggest that weaker Mg II absorption selects gas accretion from infalling cold streams or cooled gas returning from earlier processing within the galaxy, whereas stronger absorption ($W \geq 1$ Å) selects outflows, either bound or unbound. It would be useful to constrain the relative neutral gas mass density for both processes, i.e., $\Omega(\text{H I})_{\text{halo}} = \Omega(\text{H I})_{\text{infall}} + \Omega(\text{H I})_{\text{outflow}}$, to gain insight into how much galactic gas is cycled through either mechanism at a given time and how this compares to $\Omega(\text{H I})_{\text{DLA}}$ and $\Omega(\text{H I})_{\text{tot}}$.

In this *Letter*, we compute the H I mass density within galaxy halos traced by Mg II absorption, $\Omega(\text{H I})_{\text{Mg II}} \equiv \Omega(\text{H I})_{\text{halo}}$, by invoking the $N(\text{H I})$–W relation of Ménard & Chelouche (2009) to obtain the H I column density distribution function, $n(N)$, directly from the Mg II equivalent width distribution function, $n(W)$. We exclude DLAs from our calculations so that $\Omega(\text{H I})_{\text{halo}}$ budgets gas likely to be accreting and/or outflowing from galaxies but not locked up in cold neutral clouds. We apply a 1 Å bifurcation to compute $\Omega(\text{H I})_{\text{infall}}$ and $\Omega(\text{H I})_{\text{outflow}}$, and determine the W at which $\Omega(\text{H I})_{\text{infall}} = \Omega(\text{H I})_{\text{outflow}}$. Throughout we adopt a $h = 0.70$, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ cosmology.

2. COMPUTING Ω(H I) FROM Mg II

The cosmological neutral gas mass density trace by Mg II absorbers is computed from

$$\Omega(\text{H I}) = \frac{H_0}{c}\frac{\mu m_{\text{H}}}{\rho_c}\langle N(\text{H I})\rangle \frac{dN}{dz}\frac{E(z)}{(1+z)^2}, \quad (1)$$

given that,

$$\langle N(\text{H I})\rangle \frac{dN}{dz} = \int_0^\infty N n(N)\, dN, \quad (2)$$

where $n(N)$ is the H I column density distribution function, $\mu = 1.3$ is the mean molecular weight[6], ρ_c is the critical density of the universe, H_0 is the Hubble constant, m_{H} is the mass of hydrogen, $\langle N(\text{H I})\rangle$ is the mean H I column density, dN/dz is the number of systems per unit redshift, and $E(z) = H(z)/H_0 = [\Omega_M(1+z)^3 + \Omega_\Lambda]^{1/2}$.

Computing $\Omega(\text{H I})$ requires $n(N)$, which is not directly observationally known for Mg II absorbers. However, Ménard & Chelouche (2009) determined the geometric mean column density as a function of W to be $N(\text{H I}) = AW^\beta$, where $A = (3.06 \pm 0.55) \times 10^{19}$ cm^{-2} Å$^{-\beta}$ and $\beta = 1.73 \pm 0.26$ for $0.5 \leq W \leq 3$ Å and $0.5 \leq z \leq 1.4$. Employing this column density relation, we can obtain $n(N)dN$ from the equivalent width distribution, $n(W)dW$, where $n(W)$ is the number of systems with W per unit W per unit redshift.

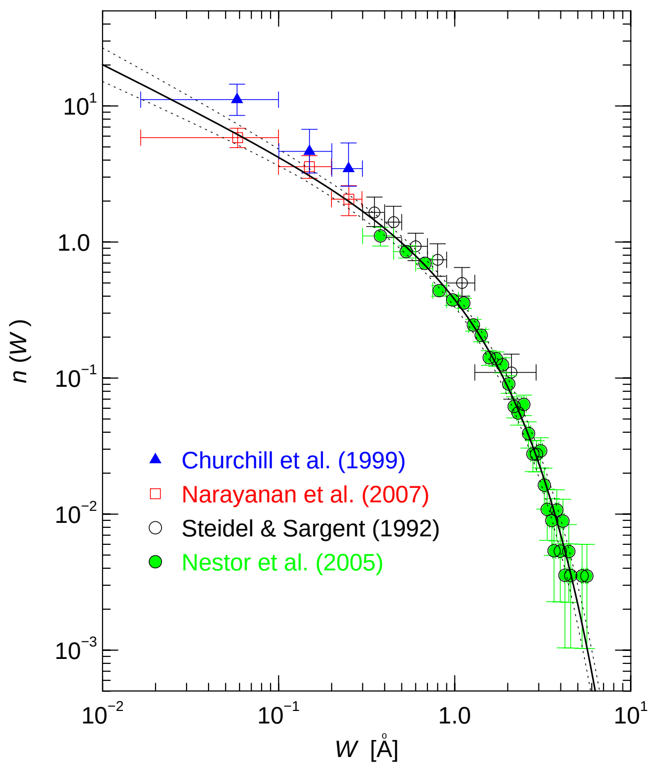

FIG. 1.— The distribution of Mg II rest-frame equivalent widths, $n(W)$, using the data from Churchill et al. (1999) [blue triangles], Narayanan et al. (2007) [red open squares], Steidel & Sargent (1992) [black open circles] and Nestor et al. (2005) [green circles]. We fitted the data using a Schechter function (solid curve). The dashed curves represent the maximum 1 σ error in the fit for the parameter uncertainties.

In Figure 1, we plot $n(W)$ versus W using the data of Steidel & Sargent (1992), Churchill et al. (1999), Nestor et al. (2005), and Narayanan et al. (2007). Since the work of Steidel & Sargent (1992), it has been common to fit $n(W)$ as either a power law or an exponential function. For $W \geq 0.3$ Å, Steidel & Sargent (1992) could not distinguish which function was preferred, whereas Nestor et al. (2005) showed that the distribution was clearly exponential. For $W \leq 0.3$ Å and $0.4 \leq z \leq 1.4$, Churchill et al. (1999) showed that $n(W)$ is a power law that is consistent with the Steidel & Sargent (1992) data for $W \leq 1.0$ Å, which was confirmed by Narayanan et al. (2007). Based upon the results discussed in § 1, we speculate the break in the $n(W)$ distribution at $W \simeq 1$ Å is physical, that infall/accretion structures yield a power law distribution whereas outflowing/wind structures yield an exponential distribution.

We used χ-squared minimization to fit the binned data to a

[6] $\mu = 1.3$ applies for a fully neutral gas and is the value used for DLA studies. For partially ionized gas, μ is slightly smaller, but still of order unity.

Schechter (1976) function (a modified Γ function),

$$n(W)dW = C_* \left(\frac{W}{W_*}\right)^{\alpha} \exp\left\{-\frac{W}{W_*}\right\} d\left(\frac{W}{W_*}\right), \qquad (3)$$

where C_* is the normalization such that the integral is equal to dN/dz (to satisfy Eq. 2). In Figure 1, we show our fit with parameters $C_* = 1.08 \pm 0.12$ Å^{-1}, $\alpha = -0.642 \pm 0.062$ and $W_* = 0.970 \pm 0.056$ Å. The *overall* equivalent width distribution at $\langle z \rangle = 1.0$ is much better fit with a Schechter function than the power law only (see Fig. 6 of Narayanan et al. 2007) or with the exponential only (see Fig. 20 of Nestor et al. 2005). We further note that the characteristic equivalent width, W_*, marking the transition from a power law to an exponential distribution is consistent with 1 Å.

There are subtle differences between the data sets shown in Figure 1. The $W < 0.3$ Å data of Churchill et al. (1999) [30 systems] and Narayanan et al. (2007) [112 systems] represent $0.4 \leq z \leq 1.4$ and have mean redshift of $\langle z \rangle = 0.9$. The $W \geq 0.3$ Å data of Steidel & Sargent (1992) [103 systems] represent $0.2 \leq z \leq 2.2$ with $\langle z \rangle = 1.1$, and the data of Nestor et al. (2005) [1331 systems] represent $0.4 \leq z \leq 2.3$, also with $\langle z \rangle = 1.1$. Thus, the redshift ranges of the $W < 0.3$ and $W \geq 0.3$ Å samples are not identical, even though the $\langle z \rangle$ are fairly consistent. Both Steidel & Sargent (1992) and Nestor et al. (2005) demonstrated redshift evolution of $n(W)$ in that there is more power at large W at higher redshifts. This evolution is expected to result in a slightly larger W_* than if we confined their samples to $z \leq 1.4$ (the upper limit of the $W < 0.3$ Å data). Given the mean redshifts of both of the $W \geq 0.3$ Å samples, $\langle z \rangle = 1.1$, are similar to those of the $W < 0.3$ Å samples, $\langle z \rangle = 0.9$, we expect that this slightly increased power in $n(W)$ has only a minor influence on our results as compared to, for example, the uncertainty in the fitted values of A and β in the column density relation of Ménard & Chelouche (2009). We also note (see Figure 1) a slight vertical offset between the two $W < 0.3$ Å data sets and between the two $W \geq 0.3$ Å data sets. The Churchill et al. (1999) data are slightly elevated over Narayanan et al. (2007) data and the Steidel & Sargent (1992) data are slightly elevated over the the Nestor et al. (2005) data (in both cases the larger surveys yield slightly smaller dN/dz). The source of the offsets is unknown.

Substituting $N(\text{H I}) = AW^{\beta}$ into Eqs. 1–3, we derive,

$$\Omega(\text{H I}) = \frac{H_0}{c}\frac{\mu m_{\text{H}}}{\rho_c}\frac{E(z)}{(1+z)^2} C_* A W_*^{\beta+1}\,\Gamma(a,w), \qquad (4)$$

where $\Gamma(a,w)$ is the incomplete gamma function, and where $a = \alpha+\beta+1$. The value of w allows integration over specific W intervals: $w = W_{max}/W_*$ for integration $0 \to w$, and $w = 0$ or W_{min}/W_* for integration $w \to \infty$, where W_{min} and W_{max} are selected cutoffs.

To compute Eq. 4, we are required to extrapolate the column density relation of Ménard & Chelouche (2009) to W values both lower and higher than the domain of their fit. Though there is scatter in the column density relation, it correctly predicts that $W < 0.3$ Å absorption systems are sub-LLS with $\log N(\text{H I}) < 17$, consistent with the findings of Churchill et al. (2000) and Rigby, Charlton, & Churchill (2002).

Rao et al. (2006) showed that the probability of a Mg II selected DLA system is $P(W) = 0$ for $W < 0.6$ Å and then increases with increasing W for $W \geq 0.6$ Å. Using a maximum-likelihood fit to the binned data in their Fig. 4, we estimate this increase as a linear function $P(W) = 0.23W - 0.057$ for $0.6 \leq W \leq 4.5$ Å with $P(W) = 1$ for $W > 4.5$ Å. In order to correct for DLA contamination in our calculation, we weight Eq. 4 by $P(W) - 1$. The upper limit of $W = 4.5$ Å where DLA contamination is 100%, is consistent with the Ménard & Chelouche (2009) column density relation, which predicts $\log N(\text{H I}) > 20.3$ for $W \geq 4.5$ Å.

TABLE 1
Ω(H I) TRACED BY Mg II AT $\langle z \rangle = 1.0$

	Ω(H I)	$\Omega(\text{H I})/\Omega(\text{H I})_{\text{DLA}}$	W range [Å]
$\Omega(\text{H I})_{\text{halo}}$	$1.41^{+0.75}_{-0.44} \times 10^{-4}$	0.147	$0.0 - \infty$
$\Omega(\text{H I})_{\text{infall}}$	$5.56^{+2.60}_{-1.54} \times 10^{-5}$	0.058	$0.0 - 1.0$
$\Omega(\text{H I})_{\text{outflow}}$	$8.57^{+0.86}_{-1.10} \times 10^{-5}$	0.089	$1.0 - \infty$
$\Omega(\text{H I})^{(w)}_{\text{Mg II}}$	$7.71^{+8.71}_{-3.88} \times 10^{-6}$	0.008	$0.0 - 0.3$

3. RESULTS AND DISCUSSION

In Table 1, we present Ω(H I) for selected W ranges. The quoted uncertainties are the 1 σ confidence levels based upon the uncertainties in the fitted parameters C_*, α, W_*, A, and β. We deduce the H I mass density traced by Mg II absorption, which is interpreted as the diffuse H I contained within galaxy halos, is $\Omega(\text{H I})_{\text{halo}} = 1.41^{+0.75}_{-0.44} \times 10^{-4}$. This value is $\sim 15\%$ of $\Omega(\text{H I})_{\text{DLA}}$, indicative that a considerable fraction of H I is contained in galaxy halos relative to the H I in DLAs; it contributes 0.3% to the total baryonic budget ($\Omega_b = 0.045$, Jarosik et al. 2011) at $\langle z \rangle = 1.0$.

We find that $W \leq 0.3$ Å Mg II absorption (often called "weak" systems, e.g., Churchill et al. 1999) selects a small fraction of the H I mass density, $\Omega(\text{H I})^{(w)}_{\text{Mg II}} = 7.71^{+8.71}_{-3.88} \times 10^{-6}$. From this quantity, it is difficult to ascertain what fraction of these systems could be selecting Lyα forest structures versus galactic halo structures because estimates of $\Omega_{\text{Ly}\alpha}$ in the appropriate N(H I) range ($10^{15.5}$–$10^{16.5}$ cm^{-2}) are highly uncertain and are quoted in units of *total* gas mass density (neutral + ionized, cf., Penton et al. 2004).

We previously described the theoretical and observational evidence supporting the idea that weaker Mg II systems trace infall/accretion and stronger systems trace outflow/winds and that $W_* \simeq 1$ Å marks the transition between the two regimes. Applying a 1 Å bifurcation to $\Omega(\text{H I})_{\text{halo}}$, we find $\Omega(\text{H I})_{\text{infall}} = 5.56^{+2.60}_{-1.54} \times 10^{-5}$ and $\Omega(\text{H I})_{\text{outflow}} = 8.57^{+0.86}_{-1.10} \times 10^{-5}$. The former is 6% of Ω_{DLA} and 0.1% of Ω_b, and latter is 9% of Ω_{DLA} and 0.2% of Ω_b. The range of W bifurcation over which the infall and outflow Ω(H I) are statistically consistent is $W = 1.23^{+0.28}_{-0.15}$ Å.

There is no *a priori* expectation that our approach to computing $\Omega(\text{H I})_{\text{halo}}$ should yield $\Omega(\text{H I})_{\text{infall}} \simeq \Omega(\text{H I})_{\text{outflow}}$ for $W \simeq W_*$. Our result may indicate that, over a redshift range covering a large percentage of the age of the universe in the "post star forming era", a cyclic balance persists between inflow and outflow of galaxies whereby star formation is fueled by accreting gas and then an equal mass of gas is ejected back into the halos. This is quite suggestive of a halo gas recycling model (e.g., Oppenheimer & Davé 2008).

Interestingly, $\Omega(\text{H I})_{\text{halo}} \simeq 13\%$ of $\Omega(\text{H I})_{\text{tot}}$, assuming[7]

[7] The simulations of Davé etal (2010) indicate that $\Omega(\text{H I}) \simeq 10^{-7}$ for $N(\text{H I}) \leq 10^{15}$ (outside halos) at $z \sim 0.1$, where the fraction of H I is at its highest.

$\Omega(\text{H I})_{\text{tot}} = \Omega(\text{H I})_{\text{halo}} + \Omega(\text{H I})_{\text{DLA}}$, which is consistent with $\Omega(\text{H I})_{<20.3}/\Omega(\text{H I})_{\text{tot}} \simeq 0.13$ at $z > 2.2$ [for H I selected gas, where $\Omega(\text{H I})_{<20.3}$ is for $N(\text{H I}) < 10^{20.3}$ cm^{-2}] (Noterdaeme et al. 2009; Péroux et al. 2005). If $\Omega(\text{H I})_{\text{DLA}}$ is constant with redshift, then the H I mass cycling through halos via infall/outflow has also remained constant. Given the cosmic evolution of the global SFR, and presuming galactic infall/outflow is strongly coupled to star formation, the global star formation must be governed by the *rate* at which H I gas cycles through halos. The observation that the mean ionization of Mg II absorbers has decreased with decreasing redshift (Bergeron et al. 1994) and prediction that the "hot" halo mass increases with decreasing redshift (Davé et al. 1999), are additional reasons to infer that the rate of the H I halo gas mass cycling through Mg II selected infall/outflow structures decreases with cosmic time if the H I mass remains constant.

Ribaudo et al. (2011) presented possible observational evidence of cold accretion in a [Mg/H] = –1.7 LLS at $z = 0.27$ near a $Z \simeq Z_{\odot}$ sub-L_{*} galaxy. Cosmological simulations predict that cold accretion is truncated at low redshifts (e.g., Fumagalli et al. 2011; Stewart et al. 2011b) such that the cross section of this gas is a tiny fraction of the observed Mg II cross section (Kacprzak et al. 2008; Chen et al. 2010a). If cold, metal-poor filaments comprise a component of the infalling material, our findings imply they constitute no more than $\sim 7\%$ of $\Omega(\text{H I})_{\text{tot}}$ at $\langle z \rangle = 1.0$.

Our calculation of $\Omega(\text{H I})_{\text{halo}}$ relies heavily on the statistical $N(\text{H I})$–W relation of Ménard & Chelouche (2009), which we extrapolated to $W = 0$ and $W = 4.5$ Å. For our calculations of $\Omega(\text{H I})_{\text{infall}}$ and $\Omega(\text{H I})_{\text{outflow}}$, we assumed the break in the $n(W)$ Schechter function at $W_{*} \simeq 1$ Å is due to infall/accretion for $W < W_{*}$ and outflowing/winds for $W > W_{*}$. Additional observations are required to ascertain whether this simple scenario has veracity. For example, there is mounting evidence that galaxy orientation plays some role in determining W (Kacprzak et al. 2011b; Bordoloi et al. 2011).

4. CONCLUSION

We have shown that the Mg II equivalent width distribution, $n(W)$, at $\langle z \rangle = 1.0$, is well described by a Schechter function. We combined our $n(W)$ with the $N(\text{H I})$–W relation of Ménard & Chelouche (2009) to compute $\Omega(\text{H I})$ residing in galactic halos, as traced by Mg II absorption (excluding DLAs). We found that 13% of $\Omega(\text{H I})_{\text{tot}}$ resides in galaxy halos and deduced that the infall and outflowing components comprise roughly equal H I mass contributions. The balance between the two may suggest that outflows are sustained by accretion and that cold accretion by filaments comprises less than $\sim 7\%$ of $\Omega(\text{H I})_{\text{tot}}$. Comparing to high redshift results, it appears that $\Omega(\text{H I})_{\text{halo}}$ has not strongly evolved over cosmic time. We argued that this implies that evolution in the cosmic SFR must depend primarily on the rate at which cool H I gas cycles through halos, even through the total H I mass cycling through halos remains fairly constant.

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