Estimating the mass density of neutral gas at $z < 1$

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ABSTRACT
We use the relationships between galactic H I mass and $B$-band luminosity determined by Rao & Briggs to recalculate the mass density of neutral gas at the present epoch based on more recent measures of the galaxy luminosity function than were available to those authors. We find $\Omega_{\text{gas}}(z = 0) \simeq 5 \times 10^{-4}$ in good agreement with the original Rao & Briggs value, suggesting that this quantity is now reasonably secure. We then show that, if the scaling between H I mass and $B$-band luminosity has remained approximately constant since $z = 1$, the evolution of the luminosity function found by the Canada-France redshift survey translates to an increase of $\Omega_{\text{gas}}$ by a factor of $\approx 3$ at $z = 0.5 - 1$. A similar value is obtained quite independently from consideration of the luminosity function of Mg II absorbers at $z = 0.65$. By combining these new estimates with data from damped Lyman $\alpha$ systems at higher redshift, it is possible to assemble a rough sketch of the evolution of $\Omega_{\text{gas}}$ over the last 90% of the age of the universe. The consumption of H I gas with time is in broad agreement with models of chemical evolution which include the effects of dust, although more extensive samples of damped Lyman $\alpha$ systems at low and intermediate redshift are required for a quantitative assessment of the dust bias.

1 INTRODUCTION
Recently there have been major strides forward in charting the progress of galaxy evolution. By combining the results of extensive redshift surveys at $z < 1$ with the density of star-forming galaxies at $z > 2$ identified via the Lyman break, Madau et al. (1996) have shown
that it is possible to track the global star formation history over most of the Hubble time. The associated production of heavy elements at $z > 2$ appears to be in good agreement with the typical metallicity of the universe at these early epochs, $Z \simeq 1/13Z_\odot$, as deduced from studies of damped Lyman $\alpha$ systems (DLAs) in QSO spectra (Pettini et al. 1997; Lu et al. 1996). Such low abundances are in turn consistent with the the low rate of neutral gas consumption implied by the observation that the mass density of gas in damped systems is approximately constant over this redshift interval (Storrie-Lombardi, McMahon, & Irwin 1996; hereafter SMI96). Thus all three strands appear to lead to a roughly consistent picture of the onset of galaxy formation in the universe.

Following these leads from $z = 2$ to the present time is difficult, however. On the one hand, bridging the gap from $z = 2$ to 1 in our knowledge of the star-formation rate is stymied by the uncertainties of photometric redshifts and the lack of distinctive spectral features in this redshift range, at least at optical wavelengths (Connolly et al. 1997). On the other hand, at $z \lesssim 1.5$ QSO absorbers become progressively less effective for tracing the abundance of neutral gas and metals. The reason for this is the paucity of damped Lyman $\alpha$ systems at low and intermediate redshifts, due to a combination of cosmological effects (reduced pathlength), intrinsic evolution and possible dust bias (Pei & Fall 1995). The seriousness of this shortage can be fully realised when one considers that only two new DLAs at $z < 1.5$ with neutral hydrogen column density $N(\text{H I}) \geq 2 \times 10^{20}$ cm$^{-2}$ have been discovered with the Hubble Space Telescope after several years of FOS and GHRS observations (Lanzetta et al. 1997). The full sample of known DLAs at $z < 1.5$ is still largely that identified by Lanzetta, Wolfe, & Turnshek (1995) from a trawl of the International Ultraviolet Explorer data archive.

In this paper we provide new estimates of the mass density of neutral gas between $z = 1$ and 0 in a way which does not rely on damped Lyman $\alpha$ systems but is based instead on the luminosity function of galaxies. Rao & Briggs (1993) conducted an extensive analysis of the literature on the H I content of galaxies of different morphological types to determine relationships between the H I mass $\mathcal{M}_{\text{H I}}$ and the $B$-band luminosity $M_B$ for galaxies at redshift $z = 0$. They then used these relations to derive the mass density of neutral hydrogen at the present epoch which, expressed as a fraction of the closure density, is $\Omega_{\text{gas}}(z = 0) \simeq 5 \times 10^{-4}$ (throughout this paper, we assume $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0.5$ and $\Lambda = 0$). This estimate of $\Omega_{\text{gas}}$ has been used extensively in comparisons with values at high redshift determined from the column density distribution of DLAs (e.g. SMI96) to show
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a significant decrease in the neutral gas content of the universe (by about a factor of 6) from $z = 2 - 3$ to the present time, presumably as a consequence of star formation.

In arriving at their measure of $\Omega_{\text{gas}}$, Rao & Briggs also established that: (i) by far the major fraction (89%) is from spiral galaxies, with the remainder in irregulars, S0s, and ellipticals; and (ii) the contribution from intergalactic H I is negligible. The latter conclusion appears to be confirmed by recent results from the Arecibo Strip Survey, an unbiased 21 cm survey with a high sensitivity to H I of low surface density (Zwaan, Briggs, & Sprayberry 1997).

Since the work of Rao & Briggs, which made use of the luminosity function of spiral galaxies by Tammann (1986), extensive new galaxy surveys have been published. In §3 of this Letter we recalculate the value of $\Omega_{\text{gas}}$ at low redshifts making use of these more recent estimates of the local galaxy luminosity function. By assuming that there are no major changes in the relationship between H I mass and $B$-band luminosity, we then extend in §4 the calculation of $\Omega_{\text{gas}}$ to $z = 1$ using the results of the Canada-France redshift survey (CFRS) of Lilly et al. (1995, 1996). Although this assumption is yet to be tested observationally (21 cm surveys of galaxies at even modest redshifts are beyond present instrumental capabilities), it turns out not to be unreasonable between $z = 0$ and 1 in the context of generalised models of cosmic chemical evolution such as those proposed by Pei & Fall (1995). In §5 we carry out an independent check on the values of $\Omega_{\text{gas}}$ at intermediate redshifts using the statistics of Mg II absorbers. Finally in §6 we compare our estimates of $\Omega_{\text{gas}}$ at different redshifts with model predictions and comment briefly on the extent to which current samples of DLAs are biased by the presence of intervening dust. Values of $\Omega_{\text{gas}}$ at different redshifts are collected in Table 1 and plotted in Figure 1.

### 2 LOCAL ESTIMATE OF $\Omega_{\text{HI}}$

The H I mass contributed locally by galaxies of various morphological types has been studied in detail by several authors (e.g. Bothun et al. 1985; Wardle & Knapp 1986; Tully 1988). From the analysis of this body of data, Rao & Briggs (1993) derived the following relationships between the H I mass and the $B$-band luminosity respectively for spirals, irregulars and E-S0s:

$$\log M_{\text{HI}} = (3.65 - 0.30 M_B) \ M_\odot$$  
$$\log M_{\text{HI}} = (2.72 - 0.36 M_B) \ M_\odot$$

(1)  
(2)
Adopting a standard Schechter fit to the luminosity function of each morphological type, the H I mass contributed is obtained by integrating,

$$\int M_{\text{H I}}(M_B) \Phi(M_B) dM_B$$

over the optical luminosity function $\Phi(M_B)$ characterized by $\phi^*$, $M^*_B$, $\alpha$ - the familiar parameters of the Schechter function. The relations between $M_{\text{H I}}$ and $M_B$ in equations (1)–(3) in conjunction with the luminosity function $\Phi(M_B)$ provide the means to compute the mass of neutral gas contributed by each morphological type. For a given morphological mix of galaxies one can then compute the total mass in neutral hydrogen; after correcting for the 25% fraction of baryons as helium nuclei, comparison with the local closure density $\rho_{\text{crit}} = 6.94 \times 10^{10} \text{ M}_\odot \text{ Mpc}^{-3}$ finally leads to the required $\Omega_{\text{gas}}$. Using this approach and the best estimates available to them for the parameters of the luminosity functions of spirals, irregulars and E-S0, Rao & Briggs (1993) deduced $\Omega_{\text{gas}}(z = 0) = (4.9^{+2.0}_{-1.2}) \times 10^{-4}$ (this value also includes as an upper limit the contribution from dwarf ellipticals). The error was estimated to be approximately 25% primarily from the uncertainties in the normalisations of the luminosity functions used ($\phi^*$ in equation (4)), but also includes an allowance for the fact that low surface brightness galaxies may be underrepresented in local samples (Rao, Turnshek, & Briggs 1995). Fall & Pei (1993) arrived at a similar value of $\Omega_{\text{gas}}(z = 0)$ by summing up the total H I mass and $B$-band luminosity in the local universe out to 5 Mpc.

3 RECENT DETERMINATIONS OF THE LOCAL LUMINOSITY FUNCTION

Extensive galaxy surveys completed recently have led to new determinations of the luminosity function of galaxies in the nearby universe. Here we recalculate $\Omega_{\text{gas}}$ using these new data for comparison with the initial estimate by Rao & Briggs.

3.1 The LCRS luminosity function

The Las Campanas Redshift Survey (LCRS) is a magnitude limited ($-23.6 \leq M_B \leq -18.1$) $r$-band field survey of $\sim 18700$ galaxies with average redshift $\langle z \rangle = 0.1$ (Shectman et al. 1996). The luminosity function of the entire sample can be fitted with Schechter parameters: $\Phi^* = (2.38 \pm 0.13) \times 10^{-3} \text{ Mpc}^{-3}$, $M^*_B = -20.90 \pm 0.02$, and $\alpha = -0.70 \pm 0.05$ (Lin et
Table 1. Variation of the neutral gas mass density with redshift. All values are for a $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0.5$, and $\Lambda = 0$ cosmology.

| $\langle z \rangle$ | $\Delta z$ | $\Omega_{\text{gas}}$ | Reference               |
|-------------------|-----------|-----------------------|-------------------------|
| 0.00              | 0.00      | $(4.9^{+2.0}_{-1.2}) \times 10^{-4}$ | Rao & Briggs 1993 |
| 0.10              | 0.0-0.2   | $(5.6 \pm 1.4) \times 10^{-4}$       | this work (LCRS)       |
| 0.10              | 0.0-0.2   | $(5.5 \pm 1.4) \times 10^{-4}$       | this work (ESP)       |
| 0.35              | 0.2-0.5   | $(1.05 \pm 0.5) \times 10^{-3}$       | this work (CFRS)       |
| 0.63              | 0.5-0.75  | $(1.35 \pm 0.6) \times 10^{-3}$       | this work (CFRS)       |
| 0.64              | 0.08-1.5  | $(7.0 \pm 4.0) \times 10^{-4}$       | Lanzetta et al. 1995 |
| 0.65              | 0.2-1.0   | $1.7 \times 10^{-3}$                    | this work (Mg II)     |
| 0.88              | 0.75-1.0  | $(1.6 \pm 0.7) \times 10^{-3}$       | this work (CFRS)       |
| 1.89              | 1.5-2.0   | $(2.05 \pm 1.2) \times 10^{-3}$       | Lanzetta et al. 1995 |
| 2.40              | 2.0-3.0   | $(2.8 \pm 0.9) \times 10^{-3}$       | Lanzetta et al. 1995 |
| 3.17              | 3.0-3.5   | $(3.0 \pm 1.5) \times 10^{-3}$       | SMI96                  |
| 4.01              | 3.5-4.7   | $(1.9 \pm 0.8) \times 10^{-3}$       | SMI96                  |

al. 1996). However, these authors pointed out that the luminosity functions of galaxies with and without emission lines are significantly different. Adopting an equivalent width of [O II] $\lambda 3727 \ W_{\text{[O II]}} = 5$ Å as the dividing line, Lin et al. deduced $\Phi^* = (1.63 \pm 0.13) \times 10^{-3}$ Mpc$^{-3}$, $M_B^* = -20.64 \pm 0.02$, and $\alpha = -0.9 \pm 0.1$ for emission line galaxies, while non-emission line galaxies are described by: $\Phi^* = (1.38 \pm 0.13) \times 10^{-3}$ Mpc$^{-3}$, $M_B^* = -20.83 \pm 0.02$, and $\alpha = -0.3 \pm 0.1$. If we assume that galaxies with $W_{\text{[O II]}} \geq 5$ Å consist of spirals and irregulars in equal proportions, while galaxies with $W_{\text{[O II]}} < 5$ Å are E and S0, we find $\Omega_{\text{gas}}(z = 0.1) = (5.6 \pm 1.4) \times 10^{-4}$. The range quoted corresponds to changing the spiral fraction (which dominates the contribution to $\Omega_{\text{gas}}$) from 35% to 65%, whereas the uncertainty arising from the formal errors to the Schechter parameters is much smaller.

### 3.2 The ESP luminosity function

The recently completed ESO Slice Project (ESP) (Zucca et al. 1997) is a survey of $\sim 3350$ galaxies with $b_J < 19.4$ and mean redshift $\langle z \rangle \simeq 0.1$ distributed over $\sim 23$ square degrees in a region near the South Galactic Pole. As for the LCRS, galaxies with and without emission lines yielded different fits to a Schechter luminosity function, although Zucca et al. deduced steeper faint-end slopes than the LCRS for both sub-samples of galaxies, $\alpha = -1.4$ and $-1.0$ respectively. Assuming the same morphological mix as for the LCRS, we deduce: $\Omega_{\text{gas}}(z = 0.1) = (5.5 \pm 1.4) \times 10^{-4}$. This is essentially the same value as derived from the LCRS, reflecting the fact that the major reservoirs of neutral gas are the bright spirals,
Figure 1. The variation of the cosmological mass density of neutral gas with redshift. Data from the different sources indicated have all been adjusted to $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$, and include a correction factor of 1.3 to account for a helium fraction of 25%. Vertical error bars show estimated 1σ errors in $\Omega_{\text{gas}}$, while the horizontal bars indicate the redshift interval to which each measurement applies. The symbols are plotted at the median redshift of each bin. The curves show the predictions of chemical evolution models by Pei & Fall (1995) with (dot-dash) and without (dash) inflow of metal-free gas.

rather than the low luminosity galaxies which dominate the counts. Similarly, the steep rise of the luminosity function at faint magnitudes ($M_B > -15$) recently proposed by Loveday (1997) has a negligible effect on $\Omega_{\text{gas}}$.

It is encouraging that the most recent, large scale galaxy surveys yield values of $\Omega_{\text{gas}}$ which are in good agreement with the original estimate by Rao & Briggs (1993). This does suggest that, unless a whole population of low surface brightness HI sources is still being missed (a possibility which seems unlikely, as discussed by Briggs 1997), the mass density of neutral gas at the present epoch is reasonably well established. Note that $\Omega_{\text{gas}}(z = 0) \simeq 5 \times 10^{-4}$ is approximately 13% of $\Omega_{\text{baryons}}$ in galaxies today (e.g. Madau et al. 1996).
4 BEYOND THE LOCAL LUMINOSITY FUNCTION

The CFRS has provided the first comprehensive estimate of the luminosity function of field galaxies out to \( z \sim 1 \). This \( I \)-band selected survey has \( \sim 590 \) secure redshifts with a median \( \langle z \rangle \approx 0.56 \). The selection in the \( I \)-band, which in the redshift range probed corresponds to the rest-frame \( V \) and \( B \) bands, enables a comparison with local field samples to be made. We use here the luminosity functions which Lilly et al. (1995) derived in three redshift intervals \((0.2 < z < 0.5, 0.5 < z < 0.75, \text{and } 0.75 < z < 1.0)\) separately for red and blue galaxies, having divided their sample at the spectral energy distribution of an Sbc galaxy. The two sub-samples such defined show markedly different evolution over the redshift range probed. While the luminosity function of red galaxies remains essentially constant in both number density and luminosity, that of blue galaxies exhibits significant evolution for \( z > 0.5 \).

If the relations between \( H \) I mass and \( B \)-band luminosity determined by Rao & Briggs (1993) also apply to galaxies up to \( z = 1 \) we can use the CFRS luminosity functions to estimate \( \Omega_{\text{gas}} \) in the three redshift bins considered by Lilly et al. (1995). Before proceeding further, it is important to ask under what conditions equations (1)–(3) may have remained roughly constant over the last \( \approx 8 \) Gyr. The first point to note here is that the \( B \)-band luminosity is indeed related to the current star formation rate, as indicated by the correlation between \( H\alpha \) luminosities and \( M_B \) found by Tresse & Maddox (1997) in CFRS galaxies at \( z \leq 0.3 \). Since the time derivative of the \( H \) I mass of a galaxy is proportional to the star formation rate (at least in a closed-box model), our assumption of no evolution in equations (1)–(3) is satisfied only if \( M_{\text{H}1} \), and by inference \( \Omega_{\text{gas}} \), decrease exponentially with time. It turns out that this is approximately the behaviour of \( \Omega_{\text{gas}} \) from \( z \sim 1 \) to the present epoch in the class of models of cosmic chemical evolution developed by Pei & Fall (1995) to interpret recent QSO absorption line measurements, as discussed in §6 below. Our working assumption may then be justified, pending an empirical determination of any redshift evolution in the relations between \( M_{\text{H}1} \) and \( M_B \).

Brinchmann et al. (1997) have used \( HST \) WFPC2 images to study the morphology of CFRS galaxies. Following their work, we have assumed that the red galaxies consist of 50% spirals and 50% E-S0s. For the blue galaxies, the morphological mix changes with redshift as follows: at \( \langle z \rangle = 0.35 \) 50% of the galaxies are spirals, 40% irregulars, and 10% E-S0s; at \( \langle z \rangle = 0.63 \) 50% are spirals and 50% irregulars; and at \( \langle z \rangle = 0.88 \) 40% are spirals and 60% irregulars. With these weightings, equations (1)–(3) and the CFRS luminosity functions then
lead to the values of $\Omega_{\text{gas}}$ listed in Table 1. The errors quoted, which amount to $\approx 40 - 50\%$, reflect the uncertainties in the Schechter parameters estimated by Lilly et al. (1995), added in quadrature. Varying the spiral fractions by $\pm 15\%$ increases the error on $\Omega_{\text{gas}}$ by less than $10\%$. Despite these uncertainties, it does appear that the evolution of the galaxy luminosity function at $z > 0.5$ translates to higher values of the mass density of neutral gas relative to $z = 0 - 0.2$, by factors of $\approx 2.5 - 3$.

5 COMPARISON WITH MG II ABSORBERS

We can obtain an independent estimate of $\Omega_{\text{gas}}$ at intermediate redshift based on the luminosity function and cross-section of the galaxies responsible for producing Mg II absorption systems in the spectra of background QSOs (Steidel, Dickinson, & Persson 1994). The key point here is that selection by Mg II doublet with rest-frame equivalent widths $W_0 > 0.3$ Å is equivalent to selecting by neutral gas cross-section with column density $N(\text{H} \, I) \gtrsim 3 \times 10^{17}$ cm$^{-2}$ (Steidel 1992). Local surveys (e.g. Zwaan et al. 1997) find that the bulk of the contribution to the H I mass is indeed from systems with $N(\text{H} \, I) \gtrsim 10^{18}$ cm$^{-2}$ and with gas masses $M_{\text{H} \, I} \approx 10^{10}$ M$_{\odot}$.

The Mg II absorber survey by Steidel et al. (1994) consists of 58 galaxies at $0.2 \leq z \leq 1.0$ and with median redshift $\langle z \rangle = 0.65$. The typical $B - K$ colour of the absorbing galaxies is that of a present-day mid-type spiral, although the full sample ranges from late-type spirals to unevolved ellipticals. There is a relationship, which is tighter in the $K$-band, between impact parameter (presumably reflecting the gaseous extent of the galaxy) and luminosity:

$$r(L) = 70 \left( \frac{L}{L^\ast} \right)^{0.2} \text{kpc}$$

(Steidel 1993). We use this scaling to obtain the H I mass as a function of $K$-band luminosity by modelling the neutral gas distribution in a galaxy as an exponential disk with a mass profile of the form:

$$\Sigma(r) = \Sigma_0 \exp\left(-\frac{r}{r_d}\right)$$

with a scale-length $r_d = 3.5$ kpc typical of our Galaxy and assuming that most of the H I mass is enclosed within a 20 kpc radius. Combining (5) and (6) we obtain:

$$\log M_{\text{H} \, I} = (8.31 - 0.08 M_K) M_{\odot}$$

which, together with the $K$-band luminosity function of the Mg II galaxies determined by Steidel et al. (1994) then leads to $\Omega_{\text{gas}}(z = 0.65) = 1.7 \times 10^{-3}$. As can be seen from Table 1,
this is in good agreement with the value deduced in §4 from the CFRS luminosity function at this redshift.

6 DISCUSSION

We have reached two main conclusions. First, the original estimate of the mass density of neutral gas at the present epoch by Rao & Briggs (1993) stands up well to the scrutiny of new large redshift surveys. We find \( \Omega_{\text{gas}}(z = 0.1) = (5.5 \pm 1.4) \times 10^{-4} \) from the these new surveys for \( H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}, q_0 = 0.5, \) and \( \Lambda = 0 \). Second, under the assumption that the relationship between \( \text{H I} \) mass and \( B \)-band luminosity has not changed significantly from \( z = 0 \) to 1, we find that \( \Omega_{\text{gas}} \) does increase with look-back time, as expected. Based on the luminosity function of CFRS galaxies, we deduce values of \( \Omega_{\text{gas}} \) at \( z \simeq 0.5 - 1 \) (between \( \sim 6 \) and \( \sim 8 \) Gyr ago in the cosmology adopted here) which are \( \approx 3 \) times higher than today’s and \( \approx 2 \) times lower than at \( z \simeq 2 - 3 \) (\( \sim 10 \) and \( \sim 11 \) Gyr ago respectively). While we do not yet know how robust our underlying assumption is, it is encouraging that an independent estimate of \( \Omega_{\text{gas}} \) at intermediate redshift, based on the properties of galaxies selected by absorption cross-section, is in good agreement with the CFRS values. Our approach has provided an independent consistency check on the stellar production rates as evidenced by the measured quantities: galaxy counts and optical luminosities, with the exponential decline in gas computed by Pei & Fall (1995).

We tentatively conclude that Figure 1 gives a reasonably accurate picture of the evolution of the neutral content of the universe over \( \sim 90\% \) of its past history.

Pei & Fall (1995) developed models of cosmic chemical evolution based on the measurements of \( \Omega_{\text{gas}} \) at \( z > 1.5 \) by Lanzetta et al. (1995) and Storrie-Lombardi et al. (1996) reproduced in Figure 1, and on the mean metallicity at these redshifts determined by Pettini et al. (1994). The models include in a self-consistent way the biasing effects of dust which become progressively more important as the average metal content of the universe increases with time. We show as broken lines in Figure 1 the decrease of \( \Omega_{\text{gas}} \) with decreasing redshift predicted by Pei & Fall (their Figure 4b), for a closed-box model of chemical evolution and a model with infall of gas (Pei & Fall also considered outflow models, but their predictions for \( \Omega_{\text{gas}} \) are essentially the same as those of closed-box models). As can be seen from Figure 1, the models fit the data well providing a consistency check, and, in particular, are a good match the new values of \( \Omega_{\text{gas}} \) which we have derived in this work. In this realisation
of the models, with relatively little consumption of H I gas through star formation until $z \approx 1.5$, inflow does not have a major effect and, given the uncertainties, it is not possible to distinguish models with infall of gas from the closed-box and outflow cases.

The estimates of $\Omega_{\text{gas}}$ deduced from the galaxy luminosity functions are not greatly affected by the presence of dust. The difference between these values and the (lower) values obtained from integrating the column density distribution of damped Lyman $\alpha$ systems should then be a measure of the degree to which intervening dust biases current DLA samples. $\Omega_{\text{DLA}}$ is expected to be systematically lower than $\Omega_{\text{gas}}$ because QSOs which happen to lie behind metal enriched, and therefore dusty, galaxies (as viewed from Earth) are preferentially missed in magnitude limited QSO samples. For the models reproduced in Figure 1 this effect is most pronounced at $z < 1.5$ and indeed there are tentative indications that $\Omega_{\text{DLA}}(z = 0.64)$ is only about 1/2 of $\Omega_{\text{gas}}$ at this redshift. However, it must be remembered that the estimate of $\Omega_{\text{DLA}}(z = 0.64)$ by Lanzetta et al. (1995) is based on only about a dozen DLAs spanning a redshift range which corresponds to three quarters of the Hubble time, and may thus be subject to substantial revision. Indeed, very recent reports that some Mg II absorbers are associated with large H I column densities suggest that the Lanzetta et al. value of $\Omega_{\text{DLA}}$ may be an underestimate (Turnshek et al. 1997). A quantitative assessment of the dust bias still awaits the identification of a statistically viable sample of intermediate redshift DLAs.

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