QSO ABSORPTION-LINE CONSTRAINTS ON INTRAGROUP HIGH-VELOCITY CLOUDS

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ABSTRACT

We show that the number statistics of moderate-redshift Mg II and Lyman limit absorbers may rule out the hypothesis that high-velocity clouds are infalling intragroup material.

Subject headings: intergalactic medium — Local Group — quasars: absorption lines

1. INTRODUCTION

The origin(s) of high-velocity clouds (HVCs), gaseous material that departs from the Galactic rotation law by more than 100 km s$^{-1}$, is a topic under debate. Undoubtedly, some HVCs arise from tidal streams (e.g., the Magellanic Stream) and from fountain processes local to the Galaxy (Wakker & van Woerden 1997). Recently, however, the hypothesis that most HVCs are distributed ubiquitously throughout the Local Group and are relics of group formation has returned to favor (Blitz et al. 1999, hereafter BSTHB; Braun & Burton 1999, hereafter BB).

In the intragroup HVC hypothesis (1) the cloud kinematics follow the Local Group standard of rest, not the Galactic standard of rest, with the exception of some HVCs related to tidal stripping or Galactic fountains (BSTHB; BB); (2) the cloud Galactocentric distances are typically 1 Mpc; (3) the extended HVC cloud complexes are presently accreting onto the Milky Way; (4) the clouds are local analogs of the Lyman limit absorbers observed in quasar spectra; (5) the clouds have masses of $10^7 M_\odot$ and greater; and (6) the metallicities are lower than expected if the material originated from blowout or fountains from the Milky Way (Bowen & Blades 1993; Wakker et al. 1999).

BSTHB suggest that there are $\sim 300$ clouds above the 21 cm $N$(H I) detection threshold of $\geq 2 \times 10^{18}$ cm$^{-2}$. These clouds have radii $\sim 15$ kpc and are ubiquitous throughout the group.

BB cataloged 65 Local Group compact high-velocity clouds (CHVCs), which represent a homogeneous subset of the HVC population discussed by BSTHB. High-resolution 21 cm observations (Braun & Burton 2000) show that the CHVCs have compact, $N$(H I) $> 10^{19}$ cm$^{-2}$, cold cores with a few km s$^{-1}$ FWHM surrounded by extended “halos” with FWHM $\sim 25$ km s$^{-1}$. The typical radius is $\sim 5$–8 kpc at the estimated distance of $\sim 700$ kpc. The BB sample is homogeneous but is not complete; they estimate that there could be as many as 200 Local Group CHVCs.

Recently, Zwaan & Briggs (2000) reported evidence in contradiction to the intragroup hypothesis. In a blind H I 21 cm survey of extragalactic groups sensitive to $N$(H I) $\sim 10^{18}$ cm$^{-2}$ (capable of detecting $\sim 10^7 M_\odot$ H I clouds), they failed to locate any extragalactic counterparts of the Local Group HVCs. This is in remarkable contrast to the numbers predicted. If intragroup HVCs exist around all galaxies or galaxy groups and the H I mass function is the same in extragalactic groups as measured locally, then Zwaan & Briggs should have detected $\sim 70$ in groups and $\sim 250$ around galaxies ($\sim 10$ and $\sim 40$ for the CHVCs, respectively).

Thus, the Zwaan & Briggs result is in conflict with the intragroup HVC hypothesis. Since the hypothesized intragroup clouds are remnants of galaxy formation and are shown to be stable against destruction mechanisms (BSTHB), they are predicted to form at very high redshifts and to be ubiquitous in galaxy groups to the present epoch. In this article we argue that the version of the intragroup HVC hypothesis presented by BSTHB is also in conflict with the observed redshift number density of moderate-redshift ($z \approx 0.5$) Mg II and Lyman limit (LL) quasar absorption line systems. We also find that the properties of the extragalactic analogs of the BB CHVCs are severely constrained.

In general, the redshift number density of a nonevolving population of objects, to be interpreted as the number per unit redshift, is written

$$\frac{dN}{dz} = C_f \frac{n \sigma c}{H_0} (1 + z)(1 + 2q_0 z)^{-1/2},$$

where $C_f$ is the covering factor, $n$ is the number density of absorbing structures, and $\sigma$ and $C_f$ are the surface area presented by each structure and its covering factor for detectable absorption. Throughout we use $H_0 = 100$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$, which gives $dN/dz \propto (1 + z)^{1/2}$.

2. Mg II SYSTEMS

The statistics of Mg II absorbers are well established at $0.3 \leq z \leq 2.2$. For rest-frame equivalent widths of $W$(Mg II) $> 0.3$ Å (“strong” Mg II absorption), Steidel & Sargent (1992) found $dN/dz = 0.8 \pm 0.2$ for $z \approx 0.5$, with a redshift dependence consistent with no evolution expectations. Normal, bright ($L \geq 0.1 L^*$) galaxies are almost always found within 40 kpc of strong Mg II absorbers (Bergeron & Boisse 1991; Bergeron, Cristiani, & Shaver 1992; Le Brun et al. 1993; Steidel, Dickinson, & Persson 1994; Steidel 1995; Steidel et al. 1997). From the Steidel et al. survey, all but three of 58 strong Mg II absorbers, detected toward 51 quasars, have identified galaxies with a coincident redshift within that impact parameter (sky projected separation
from the quasar line of sight) (see Charlton & Churchill 1996). Also it is rare to observe a galaxy with an impact parameter less than ~40 km/s kpc that does not give rise to Mg II absorption with $W_{\text{Mg II}} > 0.3$ Å (Steidel 1995). In 25 “control fields” of quasars, without observed strong Mg II absorption in their spectra, only two galaxies had impact parameters less than 40 km/s kpc (see also Charlton & Churchill 1996). As such, the regions within ~40 km/s kpc of typical galaxies account for the vast majority of Mg II absorbers above this equivalent-width threshold; there is nearly a “one-to-one” correspondence. If we accept these results, it would imply that there is little room for a contribution to $dN/dz$ from a population of intragroup clouds that have impact parameters much greater than ~40 km/s kpc.

However, the predicted cross section for Mg II absorption from the extragalactic intragroup clouds analogous to HVCs would be substantial. We quantify the over-prediction of the redshift path density by computing the ratio of $dN/dz$ of the intragroup clouds to that of Mg II-absorbing galaxies:

$$\frac{(dN/dz)_{\text{cl}}}{(dN/dz)_{\text{gal}}} = F \left( \frac{f_{\text{gal}}}{f_{\text{cl}}} \right) \left( \frac{N_{\text{cl}}}{N_{\text{gal}}} \right) \left( \frac{R_{\text{gal}}}{R_{\text{cl}}} \right)^2,$$

where $F$ is the fraction of Mg II absorbing galaxies that reside in groups having intragroup HVC-like clouds, $f_{\text{cl}}$ is the fraction of the area of the clouds and $f_{\text{gal}}$ is the fraction of the area of the galaxies that would produce $W_{\text{Mg II}} > 0.3$ Å along the line of sight, and $N_{\text{cl}}$ and $N_{\text{gal}}$ are the number of clouds and galaxies per group, respectively. The cross section of the group times the intragroup cloud covering factor, $C_\gamma R_g^2$, is equal to $N_{\text{cl}} R_g^2$. The total predicted $dN/dz$ for Mg II absorbers with $W_{\text{Mg II}} > 0.3$ Å is then

$$\left( \frac{dN}{dz} \right)_{\text{tot}} = \left( \frac{dN}{dz} \right)_{\text{gal}} \left[ 1 + \left( \frac{dN/dz}_{\text{cl}} \right)_{\text{gal}} \right].$$

If virtually all Mg II absorbers are accounted for by galaxies, it is required that $(dN/dz)_{\text{tot}} \approx (dN/dz)_{\text{gal}}$; the left-hand side of equation (2) must be very close to zero.

In the BSTHB version of the intragroup HVC model, the “best” expected values are $N_{\text{cl}} = 300$ and $R_g = 15$ kpc (BSTHB; L. Blitz, private communication); if we take $R_{\text{gal}} = 40$ kpc and $f_{\text{gal}} = 1$ (Steidel 1995), and assuming $N_{\text{gal}} = 4$, we find that the covering factor for Mg II absorption from extragalactic analogs to the Local Group HVCs would exceed that from galaxies by a factor of ~10 for $F = 1$ and $f_{\text{cl}} = 1$, giving $(dN/dz)_{\text{tot}} \approx 9$. More recently Blitz & Robishaw (2000) have suggested that sizes may be smaller ($R_g = 8$ kpc) when beam smearing is considered. Considering this as an indication of uncertainties in the BSTHB parameters, and considering $2 < N_{\text{cl}} < 6$ for the typical number of group galaxies, we find, for $F = 1$ and $f_{\text{cl}} = 1$, a range of $2 < (dN/dz)_{\text{cl}}/(dN/dz)_{\text{gal}} < 21$. This corresponds to $2.6 < (dN/\text{dz})_{\text{tot}} < 17.6$. It is unlikely that $F$ is significantly less than unity; the majority of galaxies reside in groups like the Local Group that would have HVC analogs. In order that $(dN/dz)_{\text{tot}} \approx (dN/dz)_{\text{gal}}$, $f_{\text{cl}} \ll 0.2$ is required.

It is not clear what fraction $f_{\text{cl}}$ of HVCs with $N(H I) > 10^{18}$ cm$^{-2}$ detection threshold will give rise to $W_{\text{Mg II}} > 0.3$ Å because the equivalent width is sensitive to the metallicity and internal velocity dispersion of the clouds. Based on CLOUDY (Ferland 1996) photoionization equilibrium models, a cloud with $N(H I) \approx 10^{18}$ cm$^{-2}$, subject to the ionizing metagalactic background (Haardt & Madau 1996), would give rise to Mg II absorption with $N_{\text{Mg II}} \approx 10^{14} N_{\text{II}} (Z/Z_{\odot})$ cm$^{-2}$, where $N_{\text{II}}$ is the H II column density in units of $10^{18}$ cm$^{-2}$ and $Z/Z_{\odot}$ is the metallicity in solar units. For optically thick clouds, those with $N(H I) > 10^{17.5}$ cm$^{-2}$, this result is insensitive to the assumed ionization parameter$^3$ over the range $10^{-4.5} - 10^{-1.5}$.

BSTHB expect HVCs to have $Z/Z_{\odot} \sim 0.1$. For $N_{\text{II}} = 2$ and $Z/Z_{\odot} = 0.1$, clouds with internal velocity dispersions of $\sigma_{\text{cl}} \approx 20$ km s$^{-1}$ (Doppler $b \approx 28$ km s$^{-1}$) give rise to $W_{\text{Mg II}} \approx 0.5$ Å. For $\sigma_{\text{cl}} = 10$ km s$^{-1}$ ($b = 14$ km s$^{-1}$), $W_{\text{Mg II}} = 0.3$ Å. The CHVC “halos” typically have FWHM of 29–34 km s$^{-1}$, which corresponds to $\sigma_{\text{cl}} \sim 12$–14 km s$^{-1}$ (BB). Thus it appears that most lines of sight through the BSTHB extragalactic analogs will produce strong Mg II absorption. Certainly $f_{\text{cl}} > 0.2$, so there is a serious discrepancy between the predicted $(dN/dz)_{\text{tot}}$ and the observed value.

However, if the intragroup clouds have lower metallicities, this would result in smaller $W_{\text{Mg II}}$. Unfortunately, there has been only one metallicity estimate published for an HVC, which may or may not be related to the Galaxy. Braun & Burton (2000) estimate that CHVC $125 +41-207$, with $W_{\text{Mg II}} = 0.15$ Å, has a metallicity of $0.04 < Z/Z_{\odot} < 0.07$; however, this is quite uncertain because of the effects of beam smearing on measuring the $N(H I)$ value. Because of the uncertainties, we simply state that a population of low-metallicity clouds could reduce the discrepancy between the predicted redshift density for intragroup clouds, $(dN/dz)_{\text{cl}}$, and the observed value of $(dN/dz)_{\text{tot}}$. However, then the expected number of smaller $W_{\text{Mg II}}$ systems to arise from intragroup clouds would be increased.

The observed Mg II equivalent-width distribution rises rapidly below 0.3 Å (“weak” Mg II absorbers), such that $(dN/dz)_{\text{tot}} = 2.2 \pm 0.3$ for $W_{\text{Mg II}} > 0.02$ Å at $z = 0.5$ (Churchill et al. 1999). To this equivalent-width limit Mg II absorption could be observed from intragroup HVCs with $N_{\text{II}} = 2$ and metallicities as low as $Z/Z_{\odot} = 0.0025$ [for $N_{\text{Mg II}} = 10^{11.3}$ cm$^{-2}$, $W_{\text{Mg II}}$ is independent of $\sigma_{\text{cl}}$]. However, almost all (nine out of a sample of 10) Mg II absorbers with $W_{\text{Mg II}} < 0.3$ Å do not have associated Lyman limit breaks (Churchill et al. 2000a); that is, their $N(H I)$ is more than a decade below the sensitivity of 21 cm surveys. Thus, based on available data, roughly 90% of the “weak” Mg II absorbers do not have the properties of HVCs and therefore are not analogous to the clouds invoked for the intragroup HVC scenario. If 10% of the weak Mg II absorbers are analogs to the intragroup HVCs, they would contribute an additional 0.20 to $(dN/dz)_{\text{cl}}$.

Since the BB CHVC extragalactic analogs have smaller cross sections, we should separately consider whether they would produce a discrepancy with the observed Mg II absorption statistics. BB observed $N_{\text{cl}} = 65$ and inferred a typical $R_g = 5$–8 kpc for the CHVCs; however, a complete sample might have $N_{\text{cl}} = 200$. Assuming $N_{\text{gal}} = 2$–6, $R_g = 40$ kpc, $f_{\text{gal}} = 1$, and $F = 1$ for the BB subsample of the HVC population, we obtain $0.17 f_{\text{cl}} < (dN/dz)_{\text{cl}} / (dN/dz)_{\text{gal}} < 4.0 f_{\text{cl}}$.

$^3$ The ionization parameter is the ratio of the number density of hydrogen ionizing photons to the number density of electrons, $n_e/n_H$. 

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The cores of the CHVCs have \( N(H\, i) > 10^{19} \text{ cm}^{-2} \), and they occupy only about 15% of the detected extent. For \( Z/Z_{\odot} > 0.01 \) and \( \sigma_{z} = 10 \text{ km s}^{-1} \), these cores can produce \( W(\text{Mg}\, \text{II}) \geq 0.3 \) Å over their full area. It follows that \( f_{\text{cl}} = 0.15 \), which yields \( 0.025 < (dN/dz)_{\text{cl}}/(dN/dz)_{\text{gal}} < 0.6 \). Depending on the specific parameters, there may or may not be a conflict with the observed \( (dN/dz)_{\text{tot}} \) for strong \( \text{Mg\, II} \) absorption.

The “halos” of the CHVCs have \( N(H\, i) > 10^{18} \text{ cm}^{-2} \) and, as discussed above, would produce weak \( \text{Mg\, II} \) absorption for \( Z/Z_{\odot} > 0.005 \) over most of the cloud area. This implies contribution to \( (dN/dz) \) from BB CHVC analogs that is in the range \( 0.14 < (dN/dz)_{\text{cl}} < 3.2 \). If the number were at the high end of this range, the cross section would be comparable to the observed \( (dN/dz) \) for weak \( \text{Mg\, II} \) absorbers at \( z = 0.5 \). However, as noted above when considering the BSTHB scenario, there is a serious discrepancy. Only \( \sim 10\% \) of the weak \( \text{Mg\, II} \) absorbers show a Lyman limit break, so extragalactic analogs of the BB CHVCs can only be a fraction of the weak \( \text{Mg\, II} \) population. Regions of CHVCs at larger radii, with \( N(H\, i) \) below the threshold of present 21 cm observations, are constrained to have \( Z/Z_{\odot} \ll 0.01 \) in order that they do not produce a much larger population of weak \( \text{Mg\, II} \) absorbers with Lyman limit break than is observed.

3. LYMAN LIMIT SYSTEMS

The redshift number density of Lyman limit systems (LLSs) also places strong constraints on intragroup environments that give rise to Lyman breaks in quasar spectra. This argument is not sensitive to the assumed cloud velocity dispersion and/or metallicity.

Statistically, \( dN/dz \) for \( \text{Mg\, II} \) systems is consistent (1 σ) with \( dN/dz \) for LLSs. At \( z \approx 0.5 \) LLSs have \( dN/dz = 0.5 \pm 0.3 \) (Stengler-Larrea et al. 1995), and \( \text{Mg\, II} \) systems have \( dN/dz = 0.8 \pm 0.2 \) (Steidel & Sargent 1992). Churchill et al. (2000a) found a Lyman limit break [i.e., \( N(H\, i) \geq 10^{16.8} \text{ cm}^{-2} \)] for each system in a sample of 10 having \( W(\text{Mg}\, \text{II}) > 0.3 \) Å. LL and \( \text{Mg\, II} \) absorbers have roughly the same redshift number density, and therefore \( \text{Mg\, II} \)--LL absorption must almost always arise within \( \sim 40 \text{ kpc} \) of galaxies (Steidel 1993). As such, there is little latitude for a substantial contribution to \( dN/dz \) from intragroup Lyman limit clouds.

Using equation (1) we could estimate this contribution by considering the volume density of galaxy groups and the cross section for HVC Lyman limit absorption in each. However, the volume density of groups is not well measured, particularly out to \( z = 0.5 \).

Instead we make a restrictive argument based on a comparison between the cross sections for Lyman limit absorption of \( L^{*} \) galaxies and for HVCs in a typical group (similar to the discussion of \( \text{Mg\, II} \) absorbers in §2). Again, we simply compare the values of \( C_{f} \) for the different populations of objects in a typical group. The covering factor for HVCs within the group is

\[
C_{f} = N_{\text{cl}} \frac{(R_{\text{cl}})^{2}}{(R_{\text{gr}})^{2}}.
\]

The best estimate for the BSTHB version of the intragroup HVC model, with \( N_{\text{cl}} = 300 \), \( R_{\text{cl}} = 15 \) kpc, and a group radius \( R_{\text{gr}} = 1.5 \) Mpc, gives \( C_{f} = 0.03 \) for \( N(H\, i) \approx 2 \times 10^{18} \text{ cm}^{-2} \). If instead we use the BB number of observed CHVCs, \( N_{\text{cl}} = 65 \) and \( R_{\text{cl}} = 5--8 \) kpc, we obtain a much smaller number, \( 0.0007 < C_{f} < 0.0018 \). However, if the BB sample is corrected for incompleteness such that \( N_{\text{cl}} = 200 \), these numbers increase so that \( 0.002 < C_{f} < 0.006 \).

In comparison, a typical group with \( \sim 4L^{*} \) galaxies, each with a Lyman limit-absorption cross section of \( R_{\text{gr}} \sim 40 \) kpc, would have \( C_{f} = 0.002 \). If they existed with the properties discussed, the extragalactic analogs to the BSTHB HVCs would dominate the contribution of \( L^{*} \) galaxies to the \( dN/dz \) of LLSs by at least a factor of \( \sim 15 \), and this is only considering HVC regions with \( N(H\, i) > 2 \times 10^{18} \text{ cm}^{-2} \) that are detected in the 21 cm surveys. Any extensions in area below this threshold value [down to \( N(H\, i) \sim 5 \times 10^{16} \text{ cm}^{-2} \)] would worsen the discrepancy. As such, the BSTHB hypothesis is definitely ruled out.

For regions of BB CHVCs with \( N(H\, i) > 2 \times 10^{18} \text{ cm}^{-2} \), the covering factor ranges from \( C_{f} = 0.0007 \) to 0.006 depending on assumed sizes and corrections for incompleteness. This ranges from 35% to 300% of the cross section for the \( L^{*} \) galaxies. The total observed \( dN/dz \) for Lyman limit absorption [down to \( N(H\, i) = 17 \text{ cm}^{-2} \)] is only \( \sim 0.5 \); even a 35% contribution to the Lyman limit cross section from HVCs that are separate from galaxies creates a discrepancy. This would imply that the result that most lines of sight within \( 40 \text{ kpc} \) of a typical \( L^{*} \) galaxy produce Lyman limit absorption is incorrect. This would further imply that there is a substantial population of strong \( \text{Mg\, II} \) absorbers without Lyman limit breaks (to account for \( dN/dz = 0.8 \) for strong \( \text{Mg\, II} \) absorption) or of strong \( \text{Mg\, II} \) absorbers not associated with galaxies. Both types of objects are rarely observed (Bergeron & Boissé 1991; Bergeron et al. 1992; Le Brun et al. 1993; Steidel et al. 1994; Steidel 1995; Steidel et al. 1997; Churchill et al. 2000a). Furthermore, \( C_{f} = 0.002 \) for BB CHVCs only takes into account the fraction of the BB CHVC areas with \( N(H\, i) \) larger than \( 2 \times 10^{18} \text{ cm}^{-2} \). Therefore, the extended “halos” around the CHVCs are also constrained to not contribute substantial cross section for Lyman limit absorption along extragalactic lines of sight.

4. SUMMARY

We have made straightforward estimates of the predicted redshift number density at \( z \approx 0.5 \) of \( \text{Mg\, II} \) and LL absorption from hypothetical extragalactic analogs to intragroup HVCs as expected by extrapolating from the BSTHB and BB Local Group samples. We find that it is difficult to reconcile the intragroup hypothesis for HVCs with the observed \( dN/dz \) of \( \text{Mg\, II} \) and LLSs.

The discrepancy between the \( dN/dz \) of \( \text{Mg\, II}--\text{LL} \) absorbers and the observed covering factor of “intragroup” HVCs could be reduced if the HVCs have a clumpy structure. Such a structure would result in \( \text{Mg\, II}--\text{LL} \) absorption observable only in some fraction, \( f_{\text{los}} \), of the lines of sight through the cloud. This effectively reduces the covering factor for Lyman limit absorption, or the value of \( f_{\text{cl}} \) in equation (2) for \( \text{Mg\, II} \) absorbers. Considering beam smearing in 21 cm surveys, substructures would be detected above an \( N(H\, i) > 2 \times 10^{18} \text{ cm}^{-2} \) 21 cm detection threshold if their column densities were \( N(H\, \text{los}) > 2 \times 10^{18}/f_{\text{los}} \text{ cm}^{-2} \). The predicted \( dN/dz \) for HVC-like clouds could be reduced by a factor of 10 if \( f_{\text{los}} \leq 0.1 \), giving \( N(H\, \text{los}) > 2 \times 10^{19} \text{ cm}^{-2} \). All the gas outside these higher \( H\, i \) column-density
substructures would need to be below the Lyman limit, or the arguments in § 3 would hold. It is difficult to reconcile such a density distribution with the high-resolution observations of BB CHVCs, which show diffuse halos around the core concentrations (Braun & Burton 2000), but these ideas merit further consideration.

4.1. The BSTHB Scenario

We conclude that the predicted $dn/dz$ from the hypothetical population of intragroup HVCs along extragalactic sight lines to quasars from the BSTHB scenario would exceed

1. The $dn/dz$ of Mg II absorbers with $W$(Mg II) $> 0.3$ Å. This class of absorber is already known to arise within $\sim 40$ $h^{-1}$ kpc of normal, bright galaxies (Bergeron & Boissé 1991; Bergeron et al. 1992; Le Brun et al. 1993; Steidel et al. 1994; Steidel 1995; Steidel et al. 1997).

2. The $dn/dz$ of “weak” Mg II absorbers with $0.02 < W$(Mg II) $< 0.3$ Å. In principle, weak Mg II absorption could arise from low metallicity, $0.005 < Z/Z_\odot < 0.1$, intragroup HVCs. However, the majority of observed weak systems are already known to be higher metallicity, $Z/Z_\odot \approx 0.1$, sub-Lyman limit systems (Churchill et al. 1999; J. R. Rigby, J. C. Charlton, & C. W. Churchill 2000, in preparation).

3. The $dn/dz$ of Lyman limit systems. These would be produced by all extragalactic BSTHB HVC analogs regardless of metallicity. However, most Lyman limit systems are seen to arise within $\sim 40$ $h^{-1}$ kpc of luminous galaxies (Steidel 1993; Churchill et al. 2000b).

These points do not preclude a population of infalling intragroup clouds that do not present a significant cross section for 21 cm absorption, as predicted by cold dark matter models (Klypin et al. 1999; Moore et al. 1999). In fact, such intragroup objects could be related to sub-Lyman limit weak Mg II absorbers (J. R. Rigby, J. C. Charlton, & C. W. Churchill 2000, in preparation).

4.2. The BB Scenario

The properties of the BB CHVC population are also significantly constrained by Mg II and Lyman limit absorber statistics:

1. They could produce $W$(Mg II) $> 0.3$ Å in excess of what is observed if a large incompleteness correction is applied (i.e., so that $N_{cl} = 200$) or if relatively large sizes ($R_{cl} \sim 8$ kpc) are assumed.

2. They would be expected to contribute to the $dn/dz$ of weak $W$(Mg II) $> 0.02$ Å Mg II absorption. However, based on observations (Churchill et al. 2000a) only $\sim 10\%$ of the population of weak Mg II absorbers have Lyman limit breaks. Therefore, only a small fraction of weak Mg II absorption could arise in extragalactic BB CHVC analogs.

3. The $dn/dz$ for Lyman limit absorption from the hypothesized BB CHVC population could be a significant fraction or comparable to that expected from the local environments of $L^*$ galaxies (within 40 kpc); the observed value is already consistent with that produced by the galaxies.

4. The CHVCs are observed to have a cool core with $N$(H I) $> 10^{19}$ cm$^{-2}$ surrounded by a halo that typically extends to $R_{cl} \sim 5$ kpc. It is natural to expect that the H I extends out to larger radii at smaller $N$(H I) and should produce a Lyman limit break out to the radius at which $N$(H I) $< 10^{16.8}$ cm$^{-2}$. Although there is expected to be a sharp edge to the H I disk at $N$(H I) $< 10^{17.5}$ cm$^{-2}$ or $10^{18}$ cm$^{-2}$ (Corbelli & Salpeter 1993; Maloney 1993; Dove & Shull 1994), physically we would expect that this edge would level off at $\sim 10^{17.5}$ cm$^{-2}$ such that a significant cross section would be presented at $10^{16.8} < N$(H I) $< 10^{17.5}$ cm$^{-2}$. Another possibility is that there is a sharp cutoff of the structure at $N$(H I) $\sim 2 \times 10^{18}$ cm$^{-2}$, but this is contrived.

5. Conclusion

We are forced to the conclusion that there can be only a limited number of extragalactic infalling-group HVC analogs at $z \sim 0.5$. Future data could force a reevaluation of the relationships between galaxies, Lyman limit systems, and Mg II absorbers, but it seems unlikely that the more serious inconsistencies we have identified could be reconciled in this way. A clumpy distribution of H I could be constructed that would reduce the discrepancy but would require very diffuse material (below the Lyman limit) around dense cores. Evolution in the population of HVCs is another possibility. If the extragalactic background radiation declined from $z = 0.5$ to the present, the clouds would have been more ionized in the past and therefore would have had smaller cross sections at a given $N$(H I). However, this does not explain why Zwaan & Briggs (2000) do not see the $z = 0$ extragalactic analogs to the HVCs or CHVCs. Our results are entirely consistent with theirs, and the implications are the same: the discrepancies between the Local Group HVC population and the statistics of Mg II and Lyman limit absorbers can only be reconciled if most of the extragalactic HVC analogs are within 100–200 kpc of galaxies and not at large throughout the groups.

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