ON THE VARIATION OF DEUTERIUM AND OXYGEN ABUNDANCES IN THE LOCAL INTERSTELLAR MEDIUM

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Abstract

The first observations of deuterium and oxygen in the Local Interstellar Medium (LISM) obtained with the Far Ultraviolet Spectroscopic Explorer (FUSE) can be used to search for local abundance variations. While the very limited sample of these first data may be consistent with no variations, they do offer a hint of *anti-correlated* variations between D/H and O/H. If confirmed by more data (which will require independently determined, accurate H I column densities), these hints suggest that observations of interstellar gas within a few kpc of the solar neighborhood will reveal clear signs of the evolution of the abundance of deuterium from there and then (the Big Bang), to here and now (the Local Interstellar Medium of the Galaxy).
1. Introduction

In a series of papers exploring seven lines-of-sight (LOS) in the Local Interstellar Medium (LISM) the Far Ultraviolet Spectroscopic Explorer (FUSE) team (Friedman et al. 2002; Hébrard et al. 2002; Kruk et al. 2002; Lehner et al. 2002; Lemoine et al. 2002; Sonneborn et al. 2002; Wood et al. 2002) has presented results on the column densities of D\textsubscript{I} and O\textsubscript{I} (along with N\textsubscript{I}, which will not be considered in this paper) but, not of H\textsubscript{I} (due to the absence of Ly\textsubscript{a} within the FUSE spectral range). These data, which have been summarized in Moos et al. (2002), are employed in the analysis presented here. While five of the seven absorbing clouds lie within \(\sim 80\) pc of the Sun (within the Local Bubble), the other two clouds are further away, \(\sim 100 - 200\) pc. Moos et al. (2002) conclude that it is likely the deuterium abundance is represented by a single value (\(D/H = 1.52 \pm 0.08 \times 10^{-5}\)) within the Local Bubble (\(\lesssim 100\) pc). They also claim that within the Local Bubble the D\textsubscript{I}/O\textsubscript{I} ratio is constant and they suggest that, as a result, the O\textsubscript{I} column densities can serve as a proxy for H\textsubscript{I} in the Local Bubble. The FUSE team, while cautioning that their results are subject to small number statistics, note an increasing dispersion in D\textsubscript{I}/H\textsubscript{I} with increasing distance from the Sun and suggest that this could be due to real variations among the LISM deuterium abundances. However, there is no claim of evidence for an anti-correlation between D\textsubscript{I} and O\textsubscript{I} over the very limited range in metallicity they have explored thus far.

These issues are reconsidered here. Using the FUSE data (specifically, Tables 3 & 4 of Moos et al. 2002), and the same caveats concerning the limited size of their sample, it is shown that their data is not inconsistent with small, anti-correlated variations in D/H and O/H. If so, it becomes problematic to use D\textsubscript{I}/O\textsubscript{I} as a proxy for the H\textsubscript{I} column densities undetermined from the FUSE data. The question of variation or not can only be resolved by more data, especially, to echo the conclusion of Moos et al. (2002), HST measurements.
of the HI column densities and gas velocity structure. However, if the variations suggested here are supported by further data, they offer the promise of sufficiently large D/I/O variations within a few kpc of the solar system that further FUSE data should have no trouble digging the signal out of the noise.

In §2 the FUSE data is used to address the question of variability in D/H, O/H, and D/I/O in the LISM. Having raised the possibility of variability, the correlations of D/H and D/I/O with O/H are further explored in §3 where it is suggested that D/H may be anti-correlated with O/H. In §4 two, likely extreme, forms for such variation are considered and compared and the corresponding predicted and FUSE-derived abundances of deuterium and oxygen are compared. In §5 our conclusions and the prospects for future resolution of the issues raised here are discussed.

2. Local Variability?

Of the seven LOS explored by the FUSE team, two lack estimates of the uncertainties in the HI column densities and Moos et al. (2002) exclude these from their quantitative analyses (except when considering the D/I/O column density ratios); the same path is followed here. In Figures 1 – 4 the various abundances or column density ratios are shown versus the HI column densities. Also shown are the data from two LOS (towards γ Cas and δ Ori A) taken from the literature (see Table 4 of Moos et al. 2002; Ferlet et al. 1980; Meyer et al. 1998; Meyer 2001; Jenkins et al. 1999). Those LOS with the largest HI column densities are also the most distant from the Sun, penetrating the Local Bubble and, generally, it is along these LOS that the dispersions among the abundance data are greatest. Given the small sample size (five LOS), it may be premature to take the presence of any dispersion too seriously. Nonetheless, it could be a harbinger of real variations among the abundances within the LISM. This latter possibility is explored below.
2.1. Deuterium

Fig. 1.— The deuterium abundances along several LOS in the LISM versus the corresponding H\textsc{i} column densities. The filled circles are the FUSE data (Moos \textit{et al.} 2000, Table 3), while the crosses for γ Cas and δ Ori A are from Copernicus, IUE, IMAPS & HST (see Table 4 of Moos \textit{et al.} 2002). The most distant LOS (also the highest H\textsc{i} column densities) are identified. The dotted line is at the FUSE-determined mean abundance, while the dashed line is at the BD +28\textdegree4211-excluded mean abundance suggested here (see the text).

The LISM deuterium abundances are plotted in Figure 1. According to the data in Moos \textit{et al.} (2002), the weighted mean deuterium abundance is D/H $= 1.52 \pm 0.08 \times 10^{-5}$. For this value, the reduced $\chi^2$ ($\chi^2$ per degree of freedom) is 1.3, suggesting no contradiction with the hypothesis that the data are drawn from an underlying population with fixed deuterium abundance. Note, also, that three of the five FUSE LOS have deuterium abundances within 1σ of this mean value, while the remaining two FUSE LOS have D/H
only slightly more than $1\sigma$ away (as does $\gamma$ Cas). In contrast, D/H for $\delta$ Ori A lies below this mean by more than $6\sigma$; unless the uncertainties for the column densities along this LOS have been seriously underestimated, or affected by unrecognized systematic errors, this cloud may have a significantly lower deuterium abundance than that in the LISM (Jenkins et al. 1999). Notice that of the five FUSE LOS, the one towards BD $+28^\circ 4211$, which has the lowest D/H, also has the smallest errors, thus tending to dominate the determination of the weighted mean abundance. If, instead, an unweighted mean (for all seven of the FUSE LOS) is taken, the mean shifts upward to $D/H = 1.62 \times 10^{-5}$, moving slightly further away from BD $+28^\circ 4211$, $\gamma$ Cas, and $\delta$ Ori A, but slightly closer to Feige 110. On the basis of the FUSE deuterium data alone, there is no statistical evidence for any variation in the LISM deuterium abundance. However, as will be seen next when oxygen is considered, there is some evidence that the abundances of D and/or O towards Feige 110 or BD $+28^\circ 4211$ (or both) may be anomalous. If the latter LOS is excluded from the estimate of the weighted mean deuterium abundance, then for the remaining four FUSE LOS the value increases to $D/H = 1.68 \pm 0.11 \times 10^{-5}$. This abundance, shown by the dashed line in Figure 1, provides a very good fit to the data, with a small reduced $\chi^2 = 0.46$ (3 dof). Notice that three of the five FUSE LOS pass within $1\sigma$ of this value too, but also note that BD $+28^\circ 4211$ is now nearly $3\sigma$ away.

### 2.2. Oxygen

In Figure 2 are plotted the oxygen abundances as a function of the $\text{H} \, \text{I}$ column densities for the seven FUSE LOS (five with error bars) along with $\gamma$ Cas and $\delta$ Ori A. From the data in Table 3 of Moos et al. (2002) the weighted mean for the five LOS is $O/H = 3.13 \pm 0.21 \times 10^{-4}$ (this differs slightly from the central value, 3.03, quoted in Moos et al. 2002). What is notable in this case is the very large dispersion among the oxygen...
Fig. 2.— The oxygen abundances along several LOS in the LISM versus the corresponding H\textsc{i} column densities. The symbols are as in Figure 1. The most distant LOS are identified. The dotted line is at the FUSE-determined mean abundance, while the dashed line is at the BD $+28^\circ4211$-excluded mean abundance suggested here (see the text).

abundances; the reduced $\chi^2$, for four degrees of freedom, is 4.0. In contrast to the deuterium abundances, now there is less than a 0.1% probability that these oxygen abundance data have been drawn from an underlying population with the weighted mean oxygen abundance. Notice that of the FUSE LOS only Feige 110 is within 1\,$\sigma$ of this abundance, and that BD $+28^\circ4211$ is $\sim 2\sigma$ below the mean. Although the FUSE team identifies Feige 110 as potentially anomalous in D, they find no evidence for any O-variability for this LOS (see Friedman et al. 2002). In fact, if this LOS is removed and the weighted mean oxygen abundance is calculated for the four remaining LOS, the mean abundance hardly changes at all (from 3.13 to 3.07) while the reduced $\chi^2$ increases to 5.6 (for three degrees of freedom).
It would seem that Feige 110 is not the culprit responsible for the dispersion among the 
oxygen abundances. Indeed, from Figure 2 the smoking gun seems to point to BD +28°4211 
(see, also, Moos et al. 2002). If this LOS is excluded instead, the mean oxygen abundance 
increases to $O/H = 3.9 \pm 0.3 \times 10^{-4}$ and the reduced $\chi^2$ (for 3 dof) is 0.85. As may be seen 
from Figure 2, this is a good fit to the limited data set with four of the five FUSE data 
points along with $\gamma$ Cas lying within 1$\sigma$ of this value; the two remaining FUSE LOS without 
error estimates also lie very close to this abundance. For this higher oxygen abundance 
(the dashed line in Figure 2) only $\delta$ Ori A and BD +28°4211 are “outliers”. Recall that the 
LOS to $\delta$ Ori A also was a candidate for an anomalously low deuterium abundance (see 
Figure 1), raising the possibility that the “problem” may lie with the H\textsubscript{I} column density 
determination (too high?) and not with either the D\textsubscript{I} or O\textsubscript{I} column densities. In contrast, 
for the $\gamma$ Cas LOS, while D/H is somewhat low, O/H is at the upper end of the oxygen 
abundance range, suggesting a possible anti-correlation between D and O along this LOS. 
The same anti-correlation is hinted at for the Feige 110 LOS, but for the opposite reason 
(high-D, somewhat low-O).

2.3. The D\textsubscript{I} And O\textsubscript{I} Column Densities

As the Galaxy evolves, incorporating interstellar gas into stars and returning stellar 
processed gas to the ISM, the deuterium abundance decreases (deuterium is destroyed 
in stars), while the overall metallicity, in particular the oxygen abundance, increases. At 
some level then, an anticorrelation between D/H and O/H is expected. Given the very 
local sample of interstellar gas in the FUSE data set, and the correspondingly very small 
range in observed abundances, any such variations in either D/H or O/H may be hidden 
by the statistical errors in the data. Furthermore, any systematic errors in the non-FUSE 
determinations of the H\textsubscript{I} column densities may either mask – or exaggerate – any real
Fig. 3.—The D\textsubscript{I}/O\textsubscript{I} column density ratios along several LOS in the LISM versus the corresponding H\textsubscript{I} column densities. The symbols are as in Figures 1 & 2. The dotted line is at the FUSE-determined mean ratio.

variations. To this end, the FUSE-determined D\textsubscript{I} and O\textsubscript{I} column densities can play a valuable role. The consequence of charge transfer reactions among H, D, and O in the ISM (Field & Steigman 1971) is to ensure that the D\textsubscript{I}/O\textsubscript{I} ratio reflects the gas phase ISM D/O ratio (\textit{e.g.}, the D/O ratio modulo any oxygen which may be trapped in dust). This ratio can serve as the canary in the coal mine, amplifying any existing, small anticorrelation between D and O which might be hidden in the noise of the separate D/H and O/H abundance determinations. To explore this possibility, in Figure 3 are plotted the D\textsubscript{I}/O\textsubscript{I} column density ratios as a function of the H\textsubscript{I} column densities.

For all seven of the FUSE LOS the weighted mean D\textsubscript{I}/O\textsubscript{I} ratio is 0.040 ± 0.002; this is shown by the dotted line in Figure 3. However, from Figure 3 it is easy to see, once
again, evidence for an increasing dispersion (now among the D\textsubscript{1}/O\textsubscript{1} ratios) associated with the most distant LOS. Furthermore, only two of the seven ratios (two of the five Local Bubble ratios) are within 1\(\sigma\) of this mean and our two suspect absorbing clouds, those along the LOS to BD +28\(^{\circ}\)4211 and Feige 110, are between 2\(\sigma\) and 3\(\sigma\) away (the non-FUSE clouds towards \(\gamma\) Cas and \(\delta\) Ori A are some 3 – 5 \(\sigma\) away). The reduced \(\chi^2 = 3.0\) (for 6 dof) provides no support for the hypothesis that these data are drawn from an underlying distribution with a constant D\textsubscript{1}/O\textsubscript{1} ratio. It may be worth noting that removing Feige 110 from the sample only slightly reduces the mean ratio, from 0.040 to 0.039, while the reduced \(\chi^2\) is only slightly reduced from 3.0 (for 6 dof) to 2.6 (for 5 dof). If, instead, BD +28\(^{\circ}\)4211 is removed, the mean is virtually unchanged while there is an improvement in the reduced \(\chi^2\) to 2.0; for 5 dof this still does not provide support for the hypothesis of a constant D\textsubscript{1}/O\textsubscript{1} ratio. Either the data (FUSE and non-FUSE) is contaminated by larger than estimated statistical errors, or by unidentified systematic uncertainties (or both) or, the D\textsubscript{1}/O\textsubscript{1} ratios are suggesting that there may be real abundance variations in D/H and/or O/H between and among the nearby and the more distant absorbing clouds. This latter possibility is explored next.

If, indeed, at least some of the dispersion in the D\textsubscript{1}/O\textsubscript{1} ratios uncovered above are due to real variations in the deuterium and/or oxygen abundances, it might be expected that the variations in these two abundances should be anticorrelated. However, while only a small amount of gas need be cycled through stars to produce a noticeable change in metallicity of the ISM, any observable change in the deuterium abundance requires that a significant, and significantly different fraction of the gas in some clouds has been processed through stars. As a result, it may well be that observable differences exist among oxygen abundances along different LOS in the LISM, while the changes in deuterium abundances are too small to be detected. Indeed, this is suggested by the FUSE results (see §2.1 and §2.2) where a constant D/H is consistent with the data while a constant O/H
Fig. 4. — The product of the deuterium and oxygen abundances versus the H\textsc{i} column densities. The symbols are as in Figures 1 – 3. The dashed line is at the weighted mean for the product (see the text).

is disfavored. If, however, the deuterium and oxygen abundances are both varying, and they are anti-correlated, then as an example of an extremely strong anti-correlation, their product might be nearly constant. In Figure 4 the product of the deuterium and oxygen abundances is shown (versus the H\textsc{i} column densities). Notice that, with the exception of BD +28\textdegree 4211 whose product of abundances is low, all the remaining FUSE LOS are in a rather narrow range of each other. It has already been noted that both the deuterium and the oxygen abundances for BD +28\textdegree 4211 are low, suggesting that the culprit might be the H\textsc{i} column density determination along this LOS. If so, this would be exacerbated in the product of abundances. If BD +28\textdegree 4211 is excluded, the weighted mean for the product of $y_D \equiv 10^5(D/H)$ and $y_O \equiv 10^4(O/H)$ is 6.5 ± 0.7; this is shown by the dashed line
in Figure 4. The remaining four FUSE LOS are all within 1σ of this value (and the two remaining FUSE LOS are close by) and the reduced $\chi^2 = 0.6$ (for 3 dof). Thus, although a constant D/H is entirely consistent with the FUSE data (see §2.1), there is some evidence in the same data for variations in O/H (see §2.2) which may be anticorrelated with small variations in D/H. Notice that for γ Cas, which has a deuterium abundance below the mean (see Figure 1) and an oxygen abundance at the high end of the range (see Figure 2), the product of the two abundances is completely consistent with the mean value. The same is true for Feige 110 which, in contrast, has slightly high-D and slightly low-O. Finally, note that, like BD +28°4211, δ Ori A is low both in D/H and O/H and, as a consequence, lies far from the mean of the product of deuterium and oxygen abundances.

### 3. Correlations With Oxygen?

If, as suggested above, the FUSE data hints at local abundance variations which may be anticorrelated between deuterium and oxygen, these variations should emerge when D/H, D/I/O, or $y_D \times y_O$ are compared with O/H (unless, of course, statistical or systematic errors are responsible for the suggested variations). To this end, in Figures 5 & 6 are shown D/H versus O/H and D/I/O versus O/H respectively. In these figures, for the purpose of comparison, the solar system deuterium and oxygen abundances (Geiss & Gloeckler 1998, Gloeckler & Geiss 2000; Allende-Prieto, Lambert, & Asplund 2001) are also included. Notice that considering the relatively large errors for the solar system (pre-solar nebula) deuterium abundance (Geiss & Gloeckler & Gloeckler & Geiss 2000), along with the lower, revised solar oxygen abundance of Allende-Prieto, Lambert, & Asplund (2001), the solar system abundances are not at all inconsistent with those found in the 4.6 Gyr younger gas in the LISM. Indeed, it should be kept in mind that the gas phase oxygen abundances may only be lower limits to the true ISM oxygen abundance since some oxygen may be tied up
Fig. 5.— The deuterium abundances along several LOS in the LISM versus the corresponding oxygen abundances. The symbols are as in Figures 1 – 4. The solar symbol is for the solar system (pre-solar nebula) abundances (see the text). The most distant LOS are labelled. The dotted line is at the revised mean value of the deuterium abundance recommended here \( (\text{D}/\text{H}) = 1.7 \times 10^{-5}; \) see §2.1, while the dashed line shows the D vs. O anti-correlation proposed here \( ((\text{D}/\text{H})(\text{O}/\text{H}) = 6.5 \times 10^{-9}; \) see the text and Figure 4).

in dust grains. If, for example, the suggestion of Esteban et al. (2002; see also, Esteban et al. 1998) of an 0.08 dex correction for dust were adopted, the mean LISM oxygen abundance would increase from the \( \text{H} \text{I} \) value of \( 3.9 \times 10^{-4} \) found here, to \( 4.7 \times 10^{-4} \), in excellent agreement with the solar value. At the same time, it should be noted that the photospheric value chosen here (Allende-Prieto, Lambert & Asplund 2001; see also Holweger 2001) may only be a lower bound to the pre-solar nebula abundance since over the 4.6 Gyr life of the Sun, some oxygen may have settled out of the photosphere.
Figure 5 provides a reflection of the conclusions reached in §2 that while the FUSE data may be consistent with a constant deuterium abundance, they are also not inconsistent with a small variation in deuterium abundances which is anticorrelated with a similarly small variation in oxygen abundances. This latter option receives further support in Figure 6 where it is clear that while a constant $\text{D} \, \text{I}/\text{O} \, \text{I}$ ratio is incapable of accounting for the bulk of the data, the ratios do support a variation in oxygen abundance which may either be uncorrelated with any variation in $\text{D}/\text{H}$ (dotted curve) or anticorrelated with a deuterium abundance variation (dashed curve).

Fig. 6.— The $\text{D} \, \text{I}/\text{O} \, \text{I}$ column density ratios along several LOS in the LISM versus the corresponding oxygen abundances. The symbols are as in Figure 5. The solid line is at the mean value of $\text{D} \, \text{I}/\text{O} \, \text{I}$ found in §2.3, while the dotted line assumes $\text{D}/\text{H} = 1.7 \times 10^{-5}$ is constant, and the dashed line shows the $\text{D}$ vs. $\text{O}$ anti-correlation suggested here (see the text and Figure 4).
4. Discussion

Fig. 7.— The predicted (vertical) versus observed (horizontal) oxygen abundances on the assumption of a constant deuterium abundance (eq. 2). The symbols are as in the other figures.

Since the FUSE spectral range does not include H I (or D I) Lyα, and the higher lines of the Lyman series lie on the flat part of the curve of growth for the LOS in the LISM, the FUSE team has relied on independent determinations of the H I column densities. Because of this limitation, they suggest that it might, instead, be possible to use the D I/O I column density ratios as a surrogate for the oxygen abundances. For example, since

\[ z \equiv 10^2 (D/O) = 10 y_D / y_O, \]

then provided that the deuterium abundance is constant, \( y_D = < y_D > = 1.7 \pm 0.1, \)

\[ y_O = 10 < y_D > / z = \frac{17 \pm 1}{z}, \]
so that a measurement of D/I/O/I (\(\propto z\)) leads directly to a predicted oxygen abundance. This relation is shown by the dotted curve in Figure 6. This is not at all inconsistent with the FUSE data. In this case a measurement of \(z\) leads to a predicted oxygen abundance (eq. 2) which may be compared to those derived from the FUSE (and other) observations. In Figure 7 is shown the relation between the currently available observed and predicted oxygen abundances.

Fig. 8.— The predicted (vertical) versus observed (horizontal) oxygen abundances on the assumption that D and O are anticorrelated (eq. 4). The symbols are as in the other figures.

But, a constant deuterium abundance is not required by the data. Indeed, it has been seen that the data are also consistent with small variations in, along with a rather strong anticorrelation between, deuterium and oxygen (\(\gamma_D \propto 1/\gamma_O\)). In this case,

\[
z = \frac{10 < y_D \times y_O >}{y_O^2} = \frac{65 \pm 7}{y_O^2},
\]
so that

\[ y_O = \left( \frac{65 \pm 7}{z} \right)^{1/2}. \]  

(4)

In this latter case, deuterium will vary along with oxygen so that

\[ y_D = \left( 0.1 < y_D \times y_O > z \right)^{1/2}. \]  

(5)

Fig. 9.— The predicted (vertical) versus observed (horizontal) deuterium abundances on the assumption that D and O are anticorrelated (eq. 5). The symbols are as in the other figures.

On the assumption that both D and O are varying locally, equations 2 & 3 may be used, along with the D I/O I column density ratios \( z \), to predict the oxygen and deuterium abundances (\( y_O \) and \( y_D \)). In Figures 8 & 9 these predictions are compared with the current FUSE (and other) data. Now, neither Feige 110 nor \( \gamma \) Cas is anomalous and even the solar system values are close to those predicted. The only outliers from these \( y_O \) vs. \( z \) and \( y_D \) vs.
relations are BD +28°4211 and δ Ori A. A possible source of their apparently anomalous abundances is discussed below.

On the basis of the current, very limited FUSE data set it is not possible to decide between the two options explored here (D varying or constant). To resolve this conundrum will require more data with well-determined H\textsubscript{I} column densities. The good news though, is that if indeed there are real variations in the currently very limited, very local FUSE data sample (as, perhaps, bounded by the dotted and dashed curves in Figure 6), future data from within a few kpc of the Sun should reveal statistically significant differences in the D\textsubscript{I}/O\textsubscript{I} column density ratios.

4.1. BD +28°4211 and δ Ori A

The excess dispersion in the FUSE-determined LISM abundances may be due to one or more of several possible sources. The sample is small and the statistical errors may have been underestimated. For some column densities along some LOS there may be unidentified systematic errors. Or, there may be real variations in the oxygen and deuterium abundances, even for this very local sample. The latter possibility has been explored here and it has been noted that the current data cannot exclude this option. The hypothesis of a – surprisingly strong – anticorrelation between D and O (\(y_D \propto 1/y_O\); see Figure 4) is not at all inconsistent with the FUSE data. The only outliers to this anticorrelation are BD +28°4211 and δ Ori A (see Figures 4 – 6). Along both these LOS both the deuterium and oxygen abundances are low (see also Figures 7 – 9). Moos et al. (2002) note that BD +28°4211 (as well as Feige 110) has a complex photospheric spectrum (Sonneborn et al. 2002) and that the placement of the continuum, crucial for accurate column density determinations, “was hindered by the complexity of the metal lines and the poorly known atomic data for some of the species arising in the photospheres of these stars”. Perhaps,
however, the *problem* is not with either the D\textsubscript{I} or O\textsubscript{I} column densities, but with the H\textsubscript{I} column densities along these LOS. For BD $+28^\circ$4211, a decrease of only $\sim 0.13$ dex would be sufficient to bring the abundances along this LOS into agreement (within the remaining statistical uncertainties) with our suggested anticorrelation: $y\textsubscript{D} \times y\textsubscript{O} = 6.5 \pm 0.7$. While the same may be true for $\delta$ Ori A, a somewhat larger decrease in N(H\textsubscript{I}), $\sim 0.23$ dex, would be required. It could be of value to reobserve these two LOS with a view to reexamining the H\textsubscript{I} column density determinations.

5. Conclusions

The FUSE data have been used to revisit the question of possible abundance variations in the LISM. The sample is painfully limited (seven LOS; only five with H\textsubscript{I} column density determinations with quoted uncertainties) but, within the statistical errors, the analysis presented here provides a hint of some variations in the local oxygen abundance (by the excess dispersion around the mean abundance) which may be anticorrelated with some variations in the LISM deuterium abundance. This is in contrast to the conclusions of Moos et al. (2002). Among the seven FUSE LOS and the two additional LOS considered by Moos et al. (2002), two outliers are identified: BD $+28^\circ$4211 and $\delta$ Ori A. The former, from the FUSE data set, has the smallest statistical errors for the D- and O-abundances, and thus dominates the FUSE mean abundance determinations (largely due to the very small error adopted for the non-FUSE H\textsubscript{I} column density determination). When this LOS is excluded from the sample, the mean D- and O-abundances increase slightly: $<y\textsubscript{D} > = 1.7 \pm 0.1$, $<y\textsubscript{O} > = 3.9 \pm 0.3$. The remaining FUSE data, while not inconsistent with a constant D-abundance in the LISM, still have an unexpectedly large dispersion around the mean O-abundance, suggesting that there may be real oxygen abundance variations along nearby LOS. If, indeed, there are variations in O/H in the LISM, they might be *anti*-correlated
with variations in D/H since as gas is cycled through stars deuterium is destroyed. The FUSE data set is, indeed, not inconsistent with a constant product of deuterium and oxygen abundances. If this anticorrelation is confirmed by further data, there is both good news and bad news. The bad news is that as FUSE expands its horizon beyond the LISM, it is unlikely that the ratio of D to O column densities \( z \equiv 10^2 D/O \) can serve as a surrogate for independent H column density measurements in the determination of D- and O-abundances. The good news is that even within a few kpc of the Sun, based on estimates of the oxygen and deuterium abundance gradients in the Galaxy (Martins & Viegas 2000, Chiappini & Matteucci 2000) \( y_O \) and \( y_D \) will vary sufficiently so that the amplification of their ratio, \( z \), will result in \( z \)-variations (e.g., by roughly a factor two over \( \sim 2 \) kpc) which will be more easily seen above the background of the statistical uncertainties.

It should be noted that even if the rather strong anticorrelation, consistent with the current FUSE data set, is confirmed locally, such a strong anticorrelation is unlikely to extend to much lower oxygen abundances. Indeed, as pristine gas from the early universe begins to be processed through stars, the heavy element abundances, oxygen in this case, will quickly increase from their zero primordial values before very much gas has been cycled through stars, destroying deuterium. As a result, for a long time (as measured by metallicity) the deuterium abundance will not deviate noticeably from its relic value, while the oxygen abundance will increase by orders of magnitude (the deuterium “plateau”). For example, if within the Galaxy a factor two lower oxygen abundance (than in the LISM) were accompanied by a factor two higher deuterium abundance, the result would be a D-abundance indistinguishable from the current estimates of the relic primordial D-abundance inferred from observations of gas in high redshift, low metallicity QSO Absorption Line Systems (Burles & Tytler 1998a; Burles & Tytler 1998b; O’Meara et al. 2001; Pettini & Bowen 2001; D’Odorico, Dessauges-Zavadsky & Molaro 2001; Levshakov et al. 2002). Indeed, the mean LISM D-abundance proposed here, \( y_D = 1.7 \pm 0.1 \), is already
indistinguishable from that suggested by Pettini & Bowen (2001; PB) for a high redshift 
(z ∼ 2), low metallicity ([Si/H] ∼ −2) QSOALS: $y_D$(PB) = 1.65 ± 0.35. The deuterium 
abundances derived from observations of the other QSOALS range from $y_D$(QSOALS) ≈ 2.5 
to 4.0. Therefore, it might be anticipated that future FUSE data along LOS within a 
few kpc of the Sun might be capable of mapping the evolution of deuterium back to 
the primordial deuterium plateau, providing a valuable complement to the very difficult 
searches for primordial-D in the QSOALS.

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REFERENCES


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