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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 *anticorrelated* 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 kiloparsecs 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).

Subject headings: ISM: abundances — nuclear reactions, nucleosynthesis, abundances

1. INTRODUCTION

In a series of papers exploring seven lines of sight (LOSs) 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 i and O i (along with N i, which will not be considered in this paper) but not of H i (because of the absence of Lyα 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 farther away, $\sim$100–200 pc. Moos et al. (2002) conclude that it is likely the deuterium abundance is represented by a single value for the five sight lines in the "near" LISM: $\mathrm{D/H} = 1.52 \times 10^{-5}$. While the uncertainty in this mean is $\pm 0.08 \times 10^{-5}$, a better measure of the uncertainty might be the weighted standard deviation which is $\pm 0.18 \times 10^{-5}$ (H. W. Moos 2002, private communication). It is also claimed by Moos et al. (2002) that within the Local Bubble the D i/O i ratio is constant, and they suggest that, as a result, the O i column densities can serve as a proxy for H 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 i/H 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 anticorrelation between D i and O 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 and 4 of Moos et al. 2002) and the same caveats concerning the limited size of their sample, it is shown that their data are not inconsistent with small, anticorrelated variations in D/H and O/H. If so, it becomes problematic to use O i as a proxy for the H 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 H i 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 i variations within a few kiloparsecs of the solar system that further *FUSE* data should have no trouble digging the signal out of the noise.

In § 2 the *FUSE* data are used to address the question of variability in D/H, O/H, and D i/O i in the LISM. Having raised the possibility of variability, the correlations of D/H and D i/O i with O/H are further explored in § 3, where it is suggested that D/H may be anticorrelated 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 LOSs explored by the *FUSE* team, two lack estimates of the uncertainties in the H i column densities and Moos et al. (2002) exclude these from their quantitative analyses (except when considering the D i/O i column density ratios); the same path is followed here. In Figures 1–4 the various abundances or column density ratios are shown versus the H i column densities. Also shown are the data from two LOSs (toward 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 LOSs with the largest H i column densities are also the most distant from the Sun, penetrating the Local Bubble, and generally, it is along these LOSs that the dispersions among the abundance data are greatest. Given the small sample size (five LOSs), 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*

The LISM deuterium abundances are plotted in Figure 1. According to the data in Moos et al. (2002), the weighted mean deuterium abundance is $\mathrm{D/H} = 1.52 \pm 0.08 \times 10^{-5}$. For this value, the reduced χ^2 (χ^2 per degree of freedom [dof]) is 1.3, suggesting no contradiction with the hypothesis

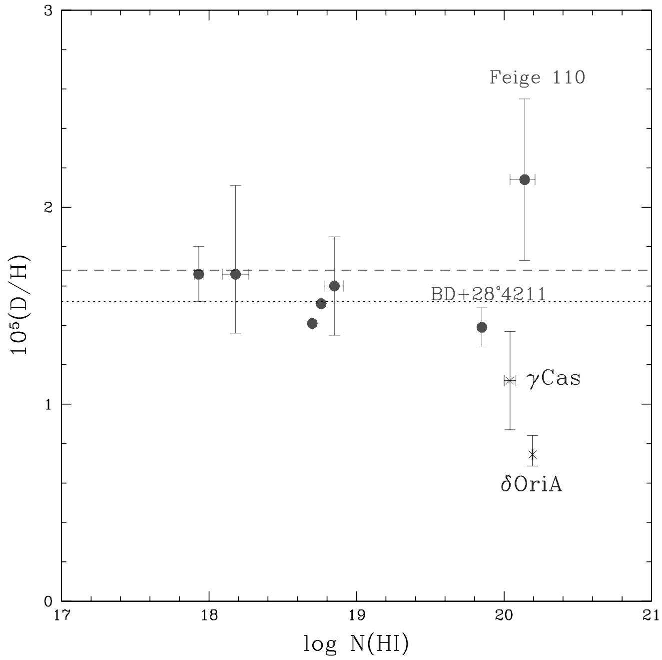

FIG. 1.—Deuterium abundances along several LOSs in the LISM vs. the corresponding H I column densities. The filled circles are the *FUSE* data (Moos et al. 2000, Table 3), while the crosses for γ Cas and δ Ori A are from *Copernicus*, *IUE*, IMAPS, and *HST* (see Table 4 of Moos et al. 2002). The most distant LOSs (also the highest H I column densities) are identified. *Dotted line*: *FUSE*-determined mean abundance. *Dashed line*: BD $+28°4211$-excluded mean abundance suggested here (see the text).

that the data are drawn from an underlying population with fixed deuterium abundance. Note also that three of the five *FUSE* LOSs have deuterium abundances within 1 σ of this mean value, while the remaining two *FUSE* LOSs have D/H only slightly more than 1 σ away (as does γ Cas). In contrast, D/H for δ Ori A lies below this mean by more than 6 σ; 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). Note that of the five *FUSE* LOSs, the one toward BD $+28°4211$, 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* LOSs) is taken, the mean shifts upward to $\mathrm{D/H} = 1.62 \times 10^{-5}$, moving slightly farther away from BD $+28°4211$, γ Cas, and δ 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 toward Feige 110 or BD $+28°4211$ (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* LOSs the value increases to $\mathrm{D/H} = 1.68 \pm 0.11 \times 10^{-5}$. 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). Note that three of the five *FUSE* LOSs pass within 1 σ of this value too, but also note that BD $+28°4211$ is now nearly 3 σ away.

2.2. *Oxygen*

In Figure 2 the oxygen abundances are plotted as a function of the H I column densities for the seven *FUSE* LOSs (five with error bars) along with γ Cas and δ Ori A. From the data in Table 3 of Moos et al. (2002) the weighted mean for the five LOSs is $\mathrm{O/H} = 3.13 \pm 0.21 \times 10^{-4}$ (this differs slightly from the value, 3.03, quoted in Moos et al. 2002, likely because of round-off errors). What is notable in this case is the very large dispersion among the oxygen abundances; the reduced χ^2 for 4 dof 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. Note that of the *FUSE* LOSs only Feige 110 is within 1 σ of this abundance and that BD $+28°4211$ is $\sim$2 σ 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 LOSs, the mean abundance hardly changes at all (from 3.13 to 3.07) while the reduced χ^2 *increases* to 5.6 (for 3 dof). 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 $\mathrm{O/H} = 3.9 \pm 0.3 \times 10^{-4}$ and the reduced χ^2 (for 3 dof) is 0.85. As can 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 γ Cas lying within 1 σ of this value; the two remaining *FUSE* LOSs without error estimates also lie very close to this abundance. For this higher oxygen abundance (Fig. 2, *dashed line*) only δ Ori A and BD $+28°4211$ are "outliers."

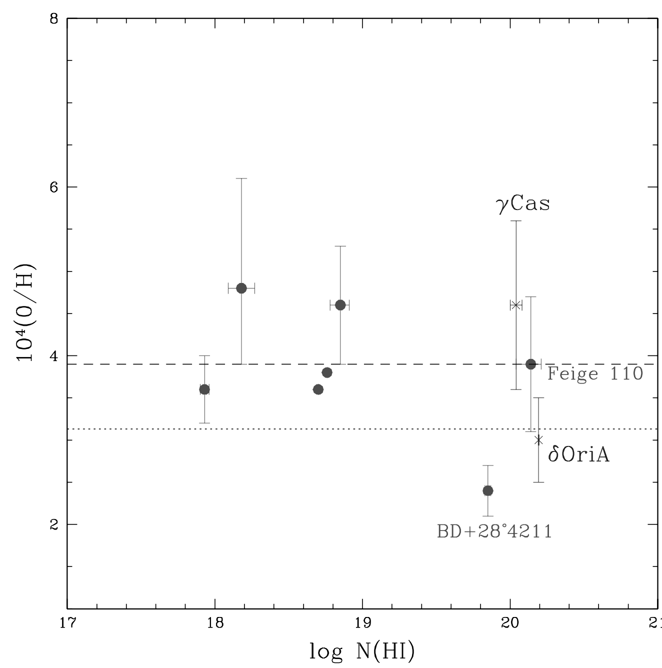

FIG. 2.—Oxygen abundances along several LOSs in the LISM vs. the corresponding H I column densities. The symbols are as in Fig. 1. The most distant LOSs are identified. *Dotted line*: *FUSE*-determined mean abundance. *Dashed line*: BD $+28°4211$-excluded mean abundance suggested here (see the text).

Recall that the LOS to δ Ori A was also a candidate for an anomalously low deuterium abundance (see Fig. 1), raising the possibility that the "problem" may lie with the H I column density determination (too high?) and not with either the D I or O I column densities. In contrast, for the γ Cas LOS, while D/H is somewhat low, O/H is at the upper end of the oxygen abundance range, suggesting a possible *anticorrelation* between D and O along this LOS. The same anticorrelation is hinted at for the Feige 110 LOS, but for the opposite reason (high D, somewhat low O).

2.3. *The* D I *and* O 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 I column densities may mask—or exaggerate—any real variations. To this end, the *FUSE*-determined D I and O 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 I/O I ratio reflects the *gas phase* ISM D/O ratio (e.g., the D/O ratio modulo any oxygen that 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 that might be hidden in the noise of the separate D/H and O/H abundance determinations. To explore this possibility, in Figure 3 the D I/O I column density ratios are plotted as a function of the H I column densities.

For all seven of the *FUSE* LOSs the weighted mean D I/O 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 I/O I ratios) associated with the most distant LOS. Furthermore, only two of the seven ratios (two of the five Local Bubble ratios) are within 1 σ of this mean and our two suspect absorbing clouds, those along the LOSs to BD $+28°4211$ and Feige 110, are between 2 and 3 σ away (the non-*FUSE* clouds toward γ Cas and δ Ori A are some 3–5 σ 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 I/O I 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 χ^2 is only slightly reduced from 3.0 (for 6 dof) to 2.6 (for 5 dof). If instead BD $+28°4211$ is removed, the mean is virtually unchanged, while there is an improvement in the reduced χ^2 to 2.0; for 5 dof this still does not provide support for the hypothesis of a constant D I/O I ratio. Either the data (*FUSE* and non-*FUSE*) are contaminated by larger than estimated statistical errors or by unidentified systematic uncertainties (or both), or the D I/O I 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 I/O I 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 the 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

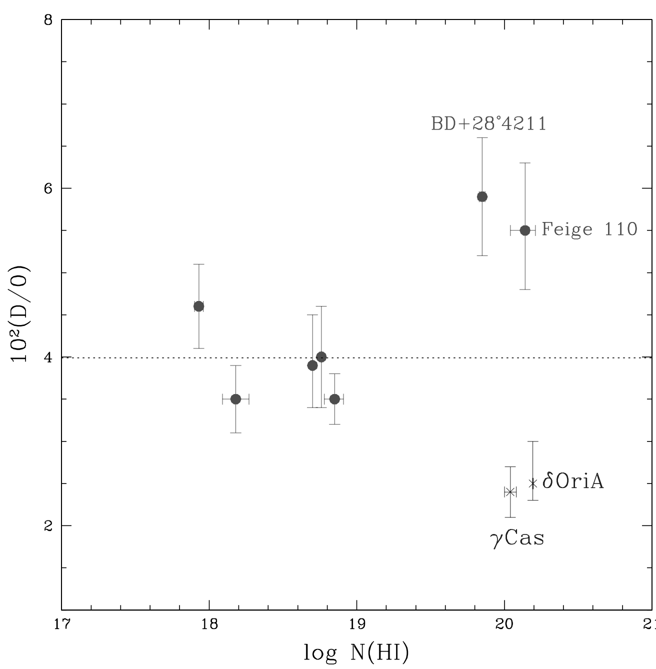

Fig. 3.—D I/O I column density ratios along several LOSs in the LISM vs. the corresponding H I column densities. Symbols are as in Fig. 1. *Dotted line*: *FUSE*-determined mean ratio.

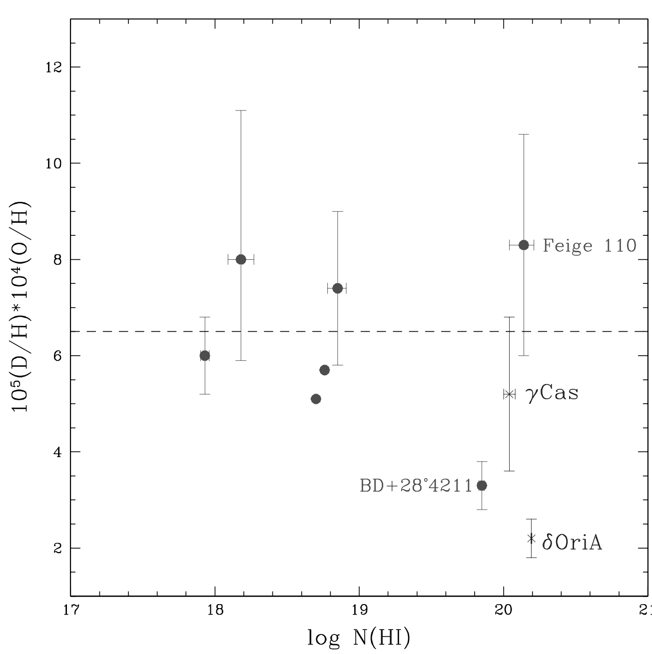

Fig. 4.—Product of the deuterium and oxygen abundances vs. the H I column densities. The symbols are as in Fig. 1. *Dashed line*: Weighted mean for the product (see the text).

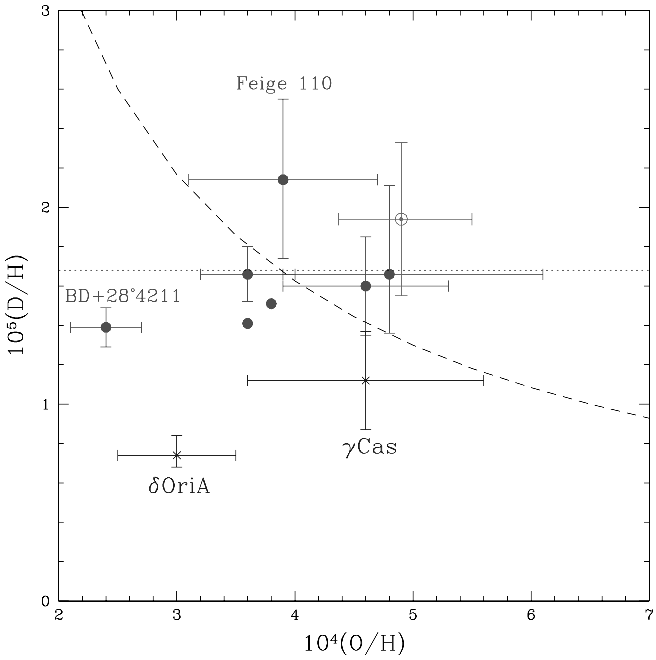

FIG. 5.—Deuterium abundances along several LOSs in the LISM vs. the corresponding oxygen abundances. The symbols are as in Fig. 1. The solar symbol is for the solar system (pre-solar nebula) abundances (see the text). The most distant LOSs are labeled. *Dotted line*: Revised mean value of the deuterium abundance recommended here (D/H $= 1.7 \times 10^{-5}$; see § 2.1). *Dashed line*: D vs. O anticorrelation proposed here [(D/H)(O/H) $= 6.5 \times 10^{-9}$; see the text and Fig. 4].

processed through stars. As a result, it may well be that observable differences exist among oxygen abundances along different LOSs 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 is disfavored. If, however, the deuterium and oxygen abundances are both varying and they are anticorrelated, then as an example of an extremely strong anticorrelation, their product might be nearly constant. In Figure 4 the product of the deuterium and oxygen abundances is shown (vs. the H I column densities). Note that, with the exception of BD +28°4211 whose product of abundances is low, all the remaining *FUSE* LOSs 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°4211 are low, suggesting that the culprit might be the H I column density determination along this LOS. If so, this would be exacerbated in the product of abundances. If BD +28°4211 is excluded, the weighted mean for the product of $y_{\rm D} \equiv 10^5$(D/H) and $y_{\rm O} \equiv 10^4$(O/H) is 6.5 ± 0.7; this is shown by the dashed line in Figure 4. The remaining four *FUSE* LOSs are all within 1 σ of this value (and the two remaining *FUSE* LOSs 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. Note that for γ Cas, which has a deuterium abundance below the mean (see Fig. 1) and an oxygen abundance at the high end of the range (see Fig. 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 in both 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 that may be anticorrelated between deuterium and oxygen, these variations should emerge when D/H, D I/O I, or $y_{\rm D} \times y_{\rm O}$ are compared with O/H (unless, of course, statistical or systematic errors are responsible for the suggested variations). To this end, in Figures 5 and 6 are shown D/H versus O/H and D I/O I 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. Note that considering the relatively large errors for the solar system (pre-solar nebula) deuterium abundance (Geiss & Gloeckler 1998 ; Gloeckler & Geiss 2000), along with the lower, revised solar oxygen abundance of Allende-Prieto et al. (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 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 H I value of 3.9×10^{-4} found here, to 4.7×10^{-4}, in excellent agreement with the solar value. At the same time, it should be noted that the photospheric value chosen here (Allende-Prieto et al. 2001; see also Holweger 2001) may only be a *lower* bound to the

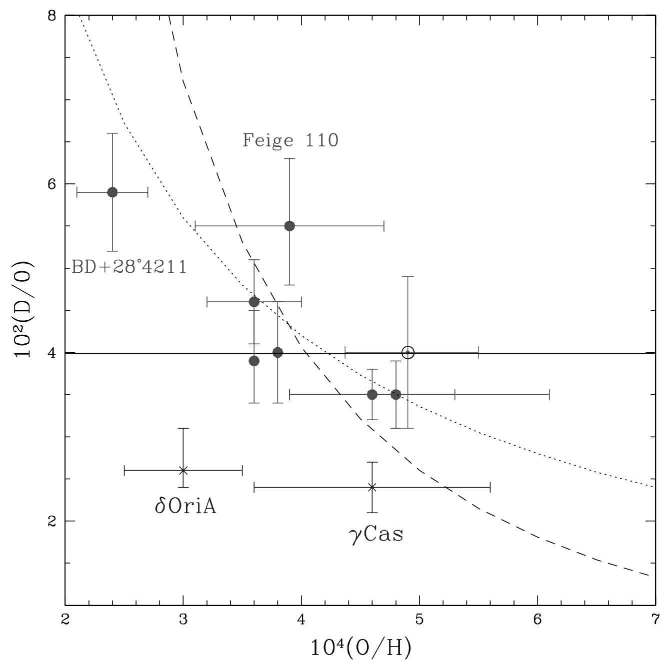

FIG. 6.—D I/O I column density ratios along several LOSs in the LISM vs. the corresponding oxygen abundances. Symbols are as in Fig. 1. The solid line is at the mean value of D I/O I found in § 2.3, while the dotted line assumes D/H $= 1.7 \times 10^{-5}$ is constant, and the dashed line shows the D vs. O anticorrelation suggested here (see the text and Fig. 4).

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 that 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 D I/O I ratio is incapable of accounting for the bulk of the data, the ratios do support a variation in oxygen abundance that may be either uncorrelated with any variation in D/H (*dotted curve*) or anticorrelated with a deuterium abundance variation (*dashed curve*).

4. DISCUSSION

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 LOSs 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 O I column densities as surrogates for the H I column densities. For example, since

$$z \equiv 10^2(\mathrm{D/O}) = 10 y_\mathrm{D}/y_\mathrm{O} \ , \tag{1}$$

then *provided that the deuterium abundance is constant*, $y_\mathrm{D} = \langle y_\mathrm{D} \rangle = 1.7 \pm 0.1$,

$$y_\mathrm{O} = \frac{10\langle y_\mathrm{D}\rangle}{z} = \frac{17 \pm 1}{z} \ , \tag{2}$$

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.

However, 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 ($y_\mathrm{D} \propto 1/y_\mathrm{O}$). In this case,

$$z = \frac{10\langle y_\mathrm{D} y_\mathrm{O}\rangle}{y_\mathrm{O}^2} = \frac{65 \pm 7}{y_\mathrm{O}^2} \ , \tag{3}$$

so that

$$y_\mathrm{O} = \left(\frac{65 \pm 7}{z}\right)^{1/2} . \tag{4}$$

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

$$y_\mathrm{D} = (0.1\langle y_\mathrm{D} y_\mathrm{O}\rangle z)^{1/2} \ . \tag{5}$$

On the assumption that both D and O are varying locally, equations (2) and (3) can 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 and 9 these predictions are compared with the current *FUSE* (and other) data.

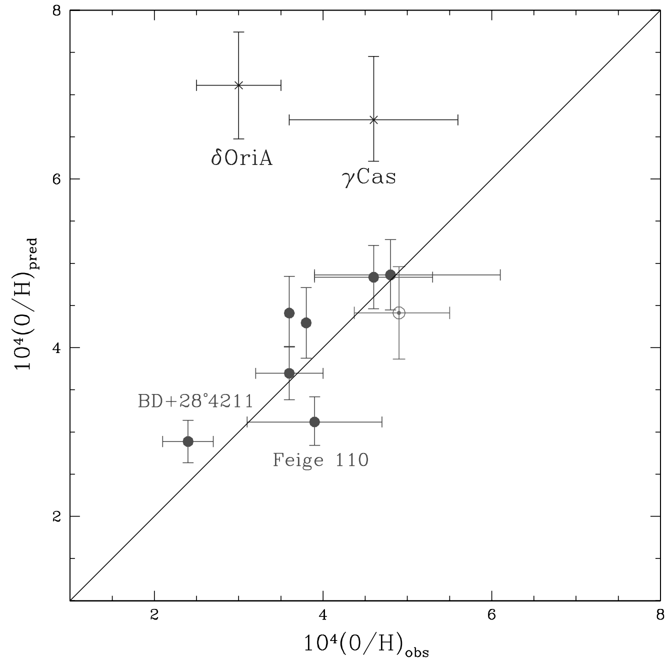

FIG. 7.—Predicted (*vertical*) vs. observed (*horizontal*) oxygen abundances on the assumption of a constant deuterium abundance (eq. [2]). The symbols are as in Fig. 1.

Now, neither Feige 110 nor γ Cas is anomalous, and even the solar system values are close to those predicted. The only outliers from these y_O versus z and y_D versus z 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

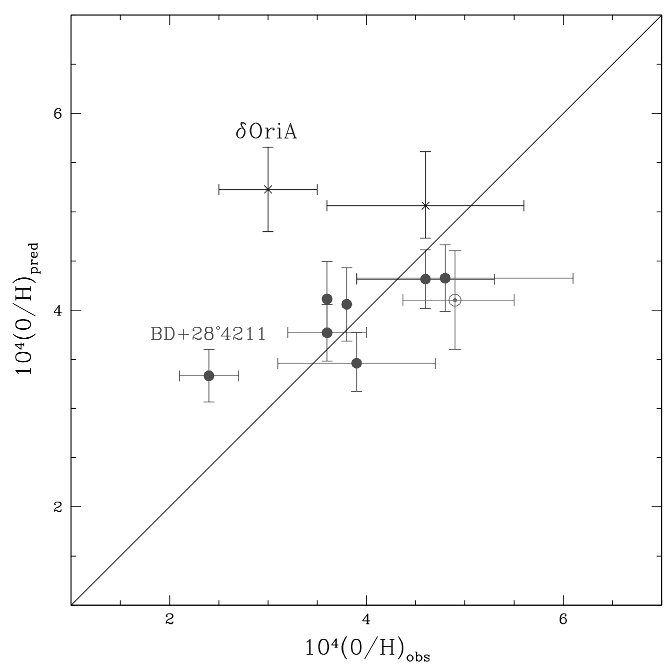

FIG. 8.—Predicted (*vertical*) vs. observed (*horizontal*) oxygen abundances on the assumption that D and O are anticorrelated (eq. [4]). The symbols are as in Fig. 1.

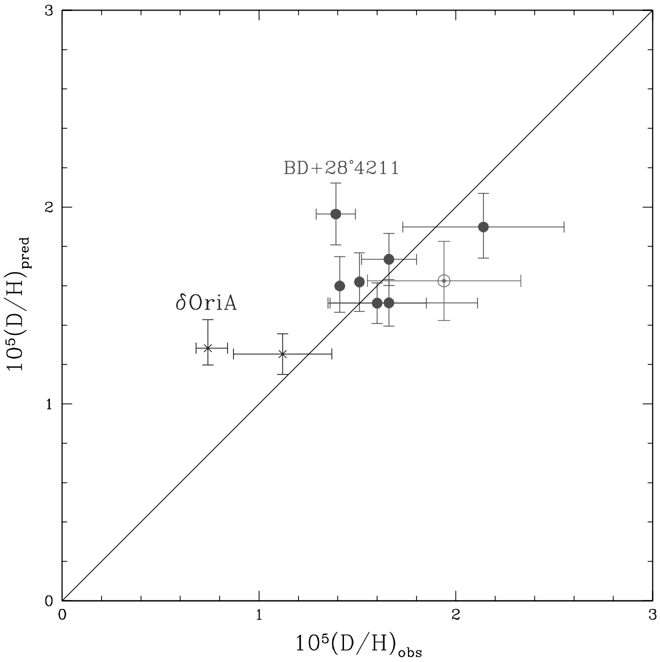

FIG. 9.—Predicted (*vertical*) vs. observed (*horizontal*) deuterium abundances on the assumption that D and O are anticorrelated (eq. [5]). Symbols are as in Fig 1.

will require more data *with well-determined* H 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 Fig. 6), future data from within a few kiloparsecs of the Sun should reveal statistically significant differences in the D I/O 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 LOSs, 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 Fig. 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 Figs. 4–6). Along *both* of these LOSs *both* the deuterium and oxygen abundances are low (see also Fig. 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." It is the case that for both BD +28°4211 and δ Ori A, the estimated abundance errors are dominated by the errors in the D I and O I column densities. As noted by the referee (2002, private communication) in δ Ori A, O I is determined from a single very weak line, while the component structure of the neutral gas toward BD +28°4211 is unknown and could result in a "low" *N*(O I) or *N*(D I) if the *b*-values vary significantly between components (*FUSE* lacks the spectral resolution to define this velocity structure). If as suggested here BD +28°4211 and δ Ori A are anomalous, it should be noted that for the former the deuterium and oxygen abundances can be reconciled with the *FUSE*-determined means by increasing *N*(D I) by 1.4 σ and *N*(O I) by 2.4 σ. For δ Ori A, while the O abundance is less than 1 σ from the mean, the D abundance differs from the mean by more than 6 σ. Especially in this latter case, it is unlikely that such a difference, if not reflecting D destruction, can be blamed on a statistical fluctuation.

Perhaps, however, the *problem* is not with either the D I or O I column densities, but with the H I column densities along these LOSs. For BD +28°4211, a decrease of only ~0.13 dex would be sufficient to bring the abundances along this LOS into agreement (within the remaining statistical uncertainties) with our suggested anticorrelation: $y_D \times y_O = 6.5 \pm 0.7$. While the same may be true for δ Ori A, a somewhat larger decrease in *N*(H I), ~0.2 dex, would be required. It must be noted, however, that such large shifts seem unlikely given the quality of the data and the H I column densities, which are so large that the broad damping wings of Lyα should provide a very good constraint on *N*(H I). It should be noted that such shifts would be more than six times the quoted statistical errors in the H I column densities. Such large changes would need to result from systematic errors, although the authors (Jenkins et al. 1999; Sonneborn et al. 2002) have been very careful in their analyses.

To shed new light on these issues it could be of value to reobserve these two LOSs (and others) with a view to reexamining the H I, O I, and D I column density determinations in order to disentangle true abundance variations from possible systematic uncertainties.

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 LOSs; only five with H 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) that 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* LOSs and the two additional LOSs considered by Moos et al. (2002), two outliers are identified: BD +28°4211 and δ 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 because of the very small error adopted for the H I column density determination). When this LOS is excluded from the sample, the mean D and O abundances increase slightly: $\langle y_D \rangle = 1.7 \pm 0.1$, $\langle y_O \rangle = 3.9 \pm 0.3$. 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 LOSs. If, indeed, there are variations in O/H in the LISM, they might be *anticorrelated* 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 I to O I column densities ($z \equiv 10^2$ D/O) can serve as a surrogate for independent H I column density measurements in the determination of D and O abundances. The good news is that even within a few kiloparsecs of the Sun, based on estimates of the oxygen and deuterium abundance gradients in the Galaxy (Martins & Viegas 2000; Chiappini & Matteucci 2000), $y_{\rm O}$ and $y_{\rm D}$ will vary sufficiently so that the amplification of their ratio, z, will result in z variations (e.g., by roughly a factor 2 over ∼2 kpc) that 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 2 lower oxygen abundance (than in the LISM) were accompanied by a factor 2 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 (QSOALSs; Burles & Tytler 1998a, 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, $y_{\rm D} = 1.7 \pm 0.1$, is already indistinguishable from that suggested by Pettini & Bowen (2001; PB) for a high-redshift ($z \sim 2$), low-metallicity ($[{\rm Si/H}] \lesssim -2$) QSOALS: $y_{\rm D}({\rm PB}) = 1.65 \pm 0.35$. The deuterium abundances derived from observations of the other QSOALSs range from $y_{\rm D}({\rm QSOALS}) \approx 2.5$ to 4.0. Therefore, it might be anticipated that future *FUSE* data along LOSs within a few kiloparsecs 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 QSOALSs.

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