Light Elements in the Universe
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The Galactic deuterium gradient

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Abstract. The Galactic deuterium abundance gradient has been determined from observations of DCN in Galactic molecular clouds. This is the only way to observe D throughout the Galaxy because the molecular clouds are not limited to the 2 kpc region around the Sun observed with FUSE and from DI. We used an astrochemistry model and the DCN/HCN ratios to estimate the underlying D/H ratios in 16 molecular clouds including five in the Galactic Center. The resulting positive Galactic D gradient and reduced Galactic Center D/H ratio imply that there are no significant Galactic sources of D, there is continuous infall of low-metallicity gas into the Galaxy, and that deuterium is cosmological.

Keywords. Galaxy: abundances; ISM: molecules, abundances; radio lines: galaxies

1. Introduction

Deuterium has been extensively studied because it is not produced via stellar nucleosynthesis and is thought to be primarily produced in the big-bang so its abundance will decrease with time and metallicity unless there are any additional sources of D. The abundance of D depends on the temperature and baryonic density during the epoch of nucleosynthesis (first 3 min). Thus any Galactic source of D would undermine its use to estimate the baryonic density of the universe and place constraints on big-bang nucleosynthesis models. In homogeneous inflationary or other flat models, the D/H ratio gives the amount of dark matter and an upper limit to the number of ν families.

"Independently of the model for chemical evolution, it is predicted that the D abundance (D/H) increases with Z if D is produced in stars, but decreases as Z increases if it is primordial: these correlations hold as a function of time and for gradients of abundances at the present time. A firm observation of the correlation of D/H with Z (e.g., a gradient in the Galaxy) would therefore tell whether D is mostly made during galactic evolution before most metals were synthesized; this test could not distinguish between production in the Big-Bang and production in the first generation of stars." (Audouze & Tinsley 1976). If D is produced via any stellar or Galactic process, then the D/H ratio would be a maximum in the GC. Conversely, if there are no Galactic sources of D, then astration would reduce the D abundance in the GC to 3×10^{-12} (Audouze *et al.* 1976).

2. Observations and results

We observed DCN and $HC^{15}N$ in 16 Galactic molecular clouds (including five Galactic Center clouds). $HC^{15}N$ was observed because the HCN line is saturated. Thus DCN/HCN = $(DCN/HC^{15}N)(^{15}N/^{14}N)$. As in Lubowich *et al.* (2000) a model with 5300 chemical reactions was used to determine the underlying D/H ratios. Our results (a positive gradient

Table 1. D/H ratios in Galactic Molecular Clouds

Source	R (kpc)	D/H (ppm)
CND	0.002	< 1
Sgr A 20 km/s	0.01	2.4 0.7
Sgr A 50 km/s	0.01	2.3 0.6
GC Arc G0.13-0.13	0.035	2.5 0.5
Sgr B2	0.100	2.9 0.9
W33	4.2	9.82.4
G34.26	5.3	4.00.8
M17	5.9	2.81.1
DR21(OH)	8.1	7.10.7
Ori KL	8.2	8.72.2
NGC 2024	8.2	9.22.0
S140	8.3	143.5
NGC 2264	8.8	7.01.4
NGC 7538	9.4	173.9
W3(OH)	9.8	205.1
Edge 2 cloud	20	< 32

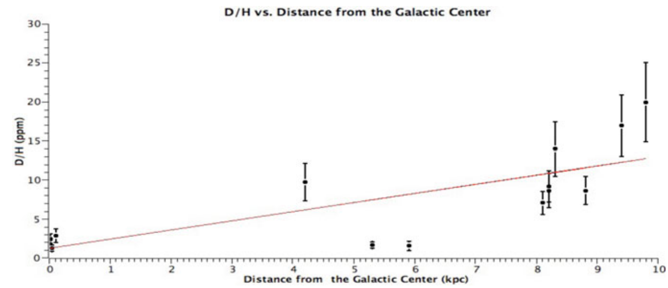

Figure 1. The Galactic Deuterium Abundance Gradient.

in the D/H ratio) are shown in Table 1 and Fig. 1 (compare to Pasachoff & Vidal-Madjar 1989). Our detection of DCN in GC molecular clouds shows D within 10-100 pc of the GC. The Sgr A clouds are 10^7 years old and contain reprocessed gas from recent star formation. Since fractionation enhances deuterated molecules, these results confirm our previous GC observations that there are no significant Galactic sources of D and that D is the result of infall of primordial gas. The low D/H ratios of 4 ppm and 2.8 ppm at 5.3 and 5.9 kpc may reflect astration in spiral arms. However, the D/H = 9.8 ppm in W33 at 4.2 kpc is not explained. At 10 kpc our results are in agreement with ISM FUSE (Linsky *et al.* 2006, 23 ppm), anticenter DI (Rogers, Dudevoir, & Bania 2007, 21 ppm, and low-metallicity halo-cloud (Sembach *et al.* 2004, 22 ppm,) D/H ratios. Better models of grain depletion, infall, astration, and astrochemistry are needed to explain the similar Galactic, quasar, and WMAP D/H ratios (26 ppm, Table 1, Linsky *et al.* 2006) while allowing large variation in the abundances of other elements. These observations are strong evidence that D is cosmological with no other significant sources of D.

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