Radio and Optical Data for Deuterium Abundances in the Galaxy

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We present spectroscopic data obtained in May with the University of Arizona 12-m radio telescope at Kitt Peak, along with a review of optical spectra taken at Kitt Peak in 1994, as part of an ongoing project to determine the D/H ratio at different points throughout the Galaxy. With the radio observations, we were able to make five-point maps of the DCN J = 2-1 (144 GHz) line in two clouds in the Sgr A region towards the galactic center, and we obtained reasonable upper limits for DNC (76.31 GHz) and DCO^+ (72.04 GHz) in a cloud in the galactic anticenter. From the optical data, we present a possible confirmation of the detection of Dα in the Orion Molecular Cloud as presented in Hébrard et al. (2000).

Introduction

Big-bang nucleosynthesis shows that the deuterium to hydrogen ratio depends very strongly on the temperature and baryonic density of the universe during the first 1000 seconds following the big bang, and measurement of the D/H ratio could determine if the baryonic density is sufficient to close the universe, as well as predicting the ratio of baryonic matter to dark matter and dark energy. It is generally thought that deuterium is not produced in stars, so over time, its abundance will decrease unless there is a nonstellar source of deuterium. Measurements of the D/H ratio in the galaxy would then put a lower limit on the primordial deuterium abundance, thus putting an upper limit on the baryonic density of the early universe (see Figure 1).

Pasachoff and Vidal-Madjar (1989) discuss how the determination of the slope of the galactic deuterium abundance gradient would indicate the probable source of the isotope. Measurements of D/H at different positions in the galaxy are effectively snapshots of the Galactic chemical evolution at different stages of galactic development, with the Galactic Center (GC) consisting of the most heavily processed material, and the outer regions of the galaxy being of essentially primordial gas. Thus, if deuterium were produced in a stellar process, one would expect to find a negative abundance gradient with the abundance to be at a maximum in the GC and decreasing with increased radial distance. Lubowich, et al. (2000) detected DCN in the SgrA 50 km/s cloud in the GC, and they compare the result with published measurements of D/H in the local interstellar medium along with a possible local detection in the galactic anticenter. They find a positive gradient and conclude that deuterium is not produced by any Galactic process. The D/H ratio they observe is higher than predicted by GC astration models, and they conclude that the resulting deuterium must come from an infall of

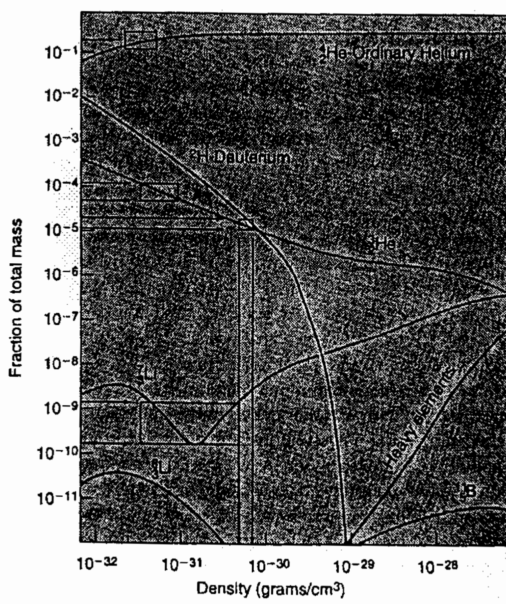

Figure 1. (Pasachoff, 2002)

primordial material. The radio observations presented here are intended to confirm this result through observations in both the Sgr A 50 and 20 km/s clouds of the GC and a cloud in the Galactic anticenter.

Observations

Radio

We observed a variety of molecular emission lines at radio frequencies in two observing runs in the spring of 2001, the first between May 12 and 20 at the Nobeyama Radio Observatory 45-m radio telescope in Japan, and the second, from May 31 to June 5 at the Steward Observatory 12-m radio telescope at Kitt Peak, Arizona. High humidity levels and high system temperatures at the Nobeyama Observatory made the detection of deuterated molecules impossible and other molecules difficult, so here we concentrate on observations made of the GC and anticenter clouds with the 12-m telescope on Kitt Peak.

We were able to make a five-point map of the DCN $J = 2\text{-}1$ transition at 144.828 GHz in both the 50 and 20 km/s clouds with observations from a central position determined by the peak CS emission (Serabyn, Lacy, and Actermann 1992) and offsets of ± 1 arcmin in both right ascension and declination. We find a peak intensity (T_R*) at the central position of the 50 km/s cloud of 38 mK to be in close agreement with the measurement of Lubowich et al. (2001). We also made similar maps of the $J = 1\text{-}0$ transition of $HC^{15}N$ at 85.055 GHz. We measure the different isotopic species of the molecules such as DCN and HCN to use in chemical modeling to ultimately determine the D/H abundance. In the anticenter, we were able to detect HCO^+ and HNC, but, after five hours of integration on each, we were able only to establish a reasonable upper limit of around 10 mK for the deuterated species, DNC and DCO^+. The map for DCN in the 50 km/s cloud is shown in Figure 2 for reference. The characteristics of the gaussian profiles fit to the lines observed using CLASS ('Continuum and Line Analysis Single-dish Software' provided by
the Institut de Radio Astronomie Millimétrique) are shown in Table 1 below.

Figure 2. Five-point map with 1′ offsets of DCN in the Sgr A 50 km/s cloud.

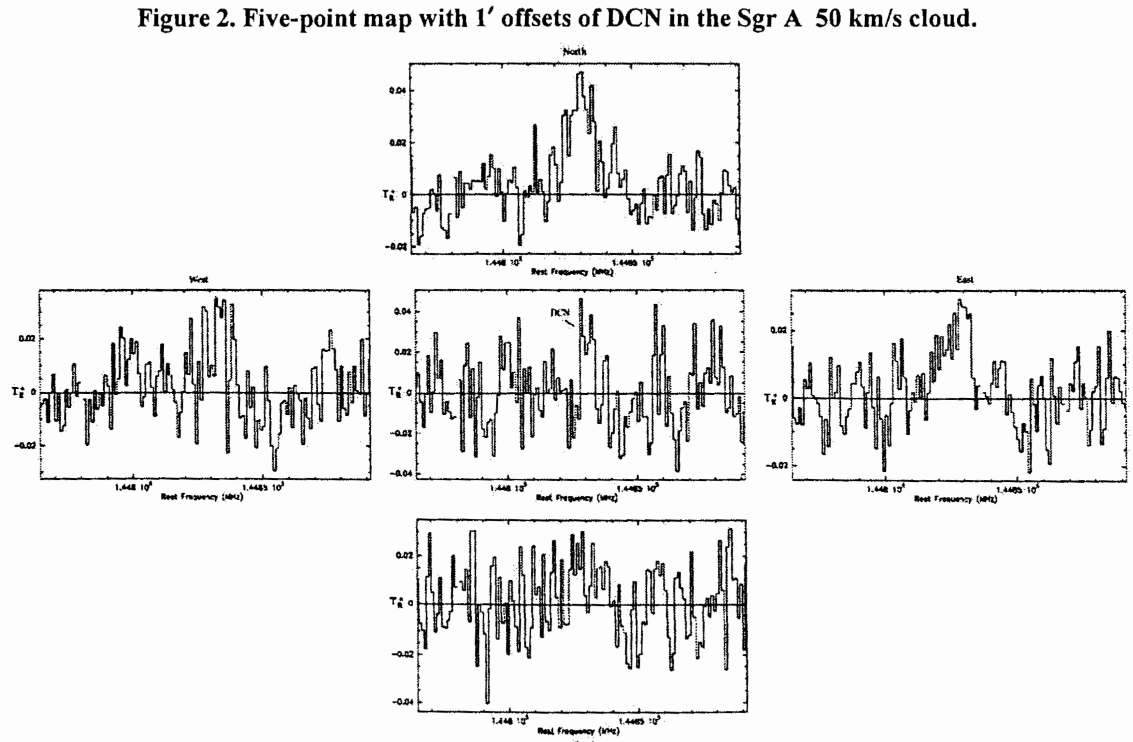

Table 1. Detected lines in the 50 km/s cloud.

Molecule	Transition	ν (MHz)	T_r^*(mK)	rms(mK)	ΔV(km/s)
center					
DCN	2-1	144828.0	38	16.8	10.3
$HC^{15}N$	1-0	85055.0	136	15.0	30.7
SO	2(2)-1(1)	86098.5	145	15.0	21.6
1' West					
DCN	2-1	144828.0	30	10.5	19.3
$HC^{15}N$	1-0	85055.0	82	41.0	39.9
SO	2(2)-1(1)	86098.5	84	41.0	27.5
1' East					
DCN	2-1	144828.0	24	9.7	18.1
$HC^{15}N$	1-0	85055.0	101	40.0	27.2
SO	2(2)-1(1)	86098.5	-	40.0	-
1' North					
DCN	2-1	144828.0	38	9.5	24.7
$HC^{15}N$	1-0	85055.0	132	42.0	31.2
SO	2(2)-1(1)	86098.5	202	42.0	20.3
1' South					
DCN	2-1	144828.0	$T_r^* < 15$ mK	15.0	-
$HC^{15}N$	1-0	85055.0	118	39.0	40.5
SO	2(2)-1(1)	86098.5	140	39	22.9

Optical

For this project, we also analyzed optical spectra taken at the Kitt Peak Coude Feed in January 1994. The data consist of forty-three 1800 s exposures of the Orion Molecular Cloud at a position 2.5 arcmin south of the trapezium star HD37022. Using IRAF, we averaged all of the exposures to create essentially one 21.5 hr observation, and we observe a bump on the red wing of the Hα line profile at a velocity shift of approximately 68 km/s redward of the central peak emission. This is a possible confirmation of the result reported by Hébrard et al. (2000) where they report the first optical detection of deuterium Balmer emission lines, and the comparison of our observation with their proposed Dα detection is shown below in Figure 3. There is some discussion regarding the true source of this emission. It is possible that there could be some line of sight velocity structure shifting the Hα emission to the position observed, but Hébrard et al. (2000) also observe other strong nebular emission lines and see no such velocity shifted emission. They also observe the feature on all of the lines in the hydrogen Balmer series up to Hη, and they conclude that it is, in fact, the deuterium Balmer series being observed.

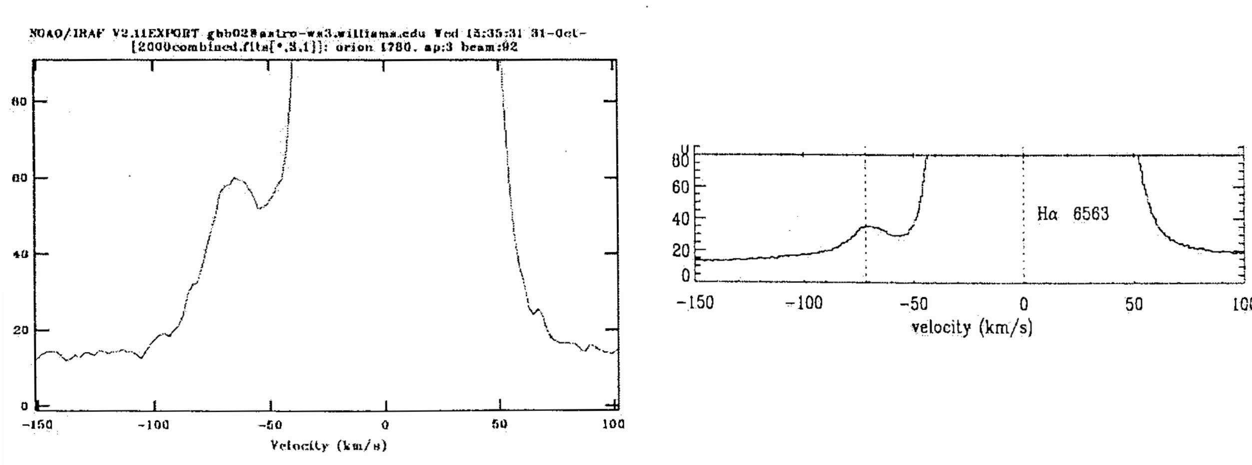

Figure 3. Comparison of our observation (left) with the Dα detection published by Hébrard et al. (2000) (right).

Future Work

The results presented above summarize the observations made for this project, and the analysis portion of the work, specifically determining the D/H ratio from the lines observed, is yet to be completed. We have some new observations of the galactic anticenter from Kitt Peak in October 2001, as well as another five days of observations from Nobeyama in January 2002 that have not yet been reduced. With more integration time we hope to detect deuterated molecules at the edge of the galaxy to establish the anticenter D/H ratio and to add another point to the galactic deuterium abundance curve.

Acknowledgments

Support for this research came from the Keck Northeast Astronomy Consortium and from Williams College. I would like to thank Dr. Aldo Apponi of the University of Arizona Steward Observatory and Dr. Shuro Takano of the Nobeyama Radio Observatory, as well as the rest of the night support staff at both observatories, for their help in making the observing runs go smoothly and successfully.

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