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The solar boron, stellar lithium and deuterium, interstellar deuterium, and extragalactic deuterium abundances

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D, Li, Be, and B are not by formed by ordinary stellar nucleosynthesis. D is primarily formed in the big bang. Because each generation of stars replenished the ISM with material depleted in D, the D abundance decreases with time and is larger in low-metallicity regions. Because Li, Be and B are primarily formed via cosmic-ray spallation reactions, their abundances will increase with time. Some Li and B is produced in supernovae via ν-spallation reactions and some Li is produced via mass loss from Li-rich AGB stars.

To determine if the B abundance has increased during past 4.5 Gyr, an accurate Solar B abundance will be determined from ongoing observations of the 1.6 μ lines of B. Initial negative results yield $B/H < 3.5 \times 10^{-10}$. The Balmer D_α line was not detected in the high-metallicity star HD 82943; the low-metallicity Pop II halo star HD 140283 (both with detected ^{6}Li); or in the slowly rotating B stars ι Her and γ Peg with $D/H < 1.0 \times 10^{-5}$. Observations of Li in super-Li-rich AGB C and S stars with strong Li lines confirms that these stars have the largest Li abundance in the Galaxy ($Li/H = 10^{-7}$ and that mass loss from these stars may contribute to the ISM Li abundance. Observations of the DCN/HCN ratio in the Galaxy yield $D/H < 1.4 \times 10^{-6}$ in the Galactic Center molecular clouds (10 pc from the center) and a positive D/H gradient in the Galaxy implying that there are no Galactic sources of D and D is cosmological. Extragalactic D (in DCN) is currently being searched for in two gravitational lenses against quasars at $z = 0.7$ and 0.9 and in the Seyfert Galaxy NGC 1068.

1. SOLAR BORON

Because B is formed from cosmic-ray or supernova ν-spallation reactions, the B/H ratio will increase with time and the present solar B/H should be larger than the meteoric B/H $= 6 \times 10^{-10}$. However, the solar B abundance $B/H = 5 \times 10^{-10}$ only known within a factor of 2 from observations of the saturated 2500 Å resonance line of BI. In order to more accurately determine the solar B abundance observations to detect the weak 1.6 μ line of BI were done with the National Solar Observatory 1.5-m telescope and Fourier Transform Spectrometer in 2000, 2001, and 2002 (Collaborators: V. Smith and J. King). Cuhna and Smith [1] reexamined the solar atlas and estimated that the weak 1.6 μ BI line may have an EW = 2 mÅ corresponding to a $B/H = 3.55 \times 10^{-10}$. We did not detect

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the 1.6 μ BI lines in the center and edge of the Sun and we plan to obtain high S/N observations of the cooler sunspots to detect these BI lines. Our initial negative results gave an EW < 2 m Å and $B/H < 3.5 \times 10^{-10}$.

2. STELLAR LITHIUM

Observations of Li in AGB C and S stars with strong Li lines at 6707 Å (EW = 8–10 Å) confirms that these stars have the largest Li abundances in the Galaxy (Li/H = 10^{-7}. The ISM Li is probably produced by cosmic-ray spallation reactions plus mass loss from Li-rich red giants (produced via $^3He(^4He,\gamma)^7Be(e,\nu)^7Li$ and ν-spallation reactions in supernovae. Based on negative results from a search for the Li and B radiofrequency hyperfine lines [2] there is no enhanced Li or B in the Galactic Center. This is consistent with the reduced Galactic Center D deuterium abundance, the current low-level cosmic-ray or γ-ray fluxes (previous weak AGN activity is not excluded). In order to understand the super-lithium-rich (SLR) phase of AGB star evolution, we will measure the Li/H and chemical composition in Galactic SLR C and S stars. High resolution echelle spectra of 3/4 C stars and 6/8 S stars have been taken at CTIO in 1998. The remaining C and S stars will be observed in 2003. Future observations include estimating the age-abundance relationship for Li-rich AGB stars in LMC clusters; determining the mass loss in SLR C and S stars from CO 2-1 and 1-0 observations; and determining if Li exists in planetary nebulae that may have evolved from Li-rich AGB stars. (Collaborators: V. Smith, C. Abia, K. Kwitter, B. E. Turner, N. Mowlavi , R. Gallino. W. Aoki, and R. Sahai)

3. DEUTERIUM

The D/H ratio is an important prediction of standard and non-homogeneous big-bang models [3] because the abundance of D depends critically on the temperature and baryonic density during the epoch of nucleosynthesis (first 1000 seconds) and might determine if the density is sufficient to close the universe. Thus any Galactic source of deuterium would undermine its use to estimate the baryonic density of the universe and place constraints on big-bang nucleosynthesis models. Alternatively, 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. Deuterium is produced by $p(p,e^+\nu)D$, $p(n,\gamma)D$ or spallation reactions between p, α, or γ-rays and He, C, N, or O and D is easily destroyed by reactions with p, n, or D. D can survive only if formed in a region of rapid expansion and cooling (big-bang or explosive nucleosynthesis) or in cool rarefied gas (ISM). The D abundance will be larger in the past at larger red-shifts representing less evolved low-metallicity gas and will decrease with time. Any non-cosmological deuterium would be a signature of high-energy astrophysical processes and a probe for analyzing, cosmic-ray physics, Galactic chemical evolution, and interstellar chemistry (with deuterated molecules). In stellar interiors D is destroyed at $T > 5 \times 10^5$ K and is converted into ^3He and ^4He during the p-p cycle. Because of astration each generation of stars replenishes the ISM with gas depleted in D.

Because stars earlier than B4 should have some D remaining in their atmospheres, a search was made for D in the atmospheres of slowly rotating sharp lined B stars in which the surface B was not destroyed at $T > 2.5 \times 10^6$ via convection to the hotter layers. We did not detect the 6561 Å Balmer D_α line (-82 km/s or -1.78 Å from H_α) in ι Her (B3IV) or γ Peg (B4V) with $D/H < 1 \times 10^{-5}$) [4]. Searches for D_α in the high-metallicity star HD 82943 (G0V; [Fe/H] = 0.32) [collaborator Lew Hobbs] and the metal-poor halo star HD 140283 (G2IV; [Fe/H] = -2.6) also gave $D/H < 1 \times 10^{-5}$) [5]. Since ^{6}Li has been detected in these stars the gas must have been at $5 \times 10^5 < T < 10^6$ K to have destroyed the D.

DCN has been detected in the Sgr A 50 km/s molecular cloud (10 pc from the Galactic Center) with an estimated $D/H = 1.7 \times 10^{-6}$ from a 5260-chemical reaction model [6]. DCN is the best molecule to use because it is efficiently synthesized at higher temperatures and chemical fractionation will enhance the abundances of deuterated molecules by up to 10,000 times over the D/H ratio. The Galactic Center (GC) D/H ratio is 9× lower than the local ISM value ($D/H = 1.5 \times 10^{-5}$) but 340,000 times larger than predicted from models without an additional source of D ($D/H = 4 \times 10^{-12}$). We have confirmed this result with additional observations of DCN in the Sgr A 50 km/s, Sgr 20 km/s, and Sgr B2 molecular clouds where we obtain an average $D/H = 1.4 \times 10^{-6}$. We conclude that there are no significant Galactic Center sources of D, the GC D comes from recent infall of low-metallicity gas, and that the GC has not had recent AGN activity or large fluxes of cosmic-rays or γ-rays. Ongoing observations of DCN in the circumnuclear ring are in progress (with the IRAM 30-m telescope) to determine if D is produced by the GC black hole via cosmic-ray or γ-ray spallation reactions. We have determined the Galactic D/H distribution from observations of DCN and $HC^{15}N$ in 15 sources and used our chemical model and the $^{14}N/^{15}N$ ratio to determine the D/H ratio. We measured a positive Galactic gradient in D/H confirming that there are no Galactic sources of D, but the analysis is complicated by chemical effects. We also have made the first detection of $D^{13}CN$ which can yield the $^{12}C/^{13}C$ ratio. We expect to make the first detection of the 92-cm lines of D I line and OD in molecular clouds in which D_2CO, NHD_2, or ND_3 have already been detected to test models of astrochemistry.

Using the Nobeyama mm array in 2003 we will search for DCN in AGN to determine if D is cosmological. We will determine the D/H ratio in the Seyfert Galaxy NGC 1068 to test models that predict enhanced D from γ-rays or cosmic-ray spallation reactions in jets. Ongoing searches for red shifted DCN and DCO^+ in absorption against gravitational lenses at $z = 0.7$ and 0.9 (optically thick lines of HCN and HCO^+ have already been detected) are being conducted with the Haystack 37-m and U. Arizona 12-m telescopes. (Collaborators: T J. Millar, C .Henkel, H. Roberts, G. Brammer, J. Pasachoff, R. Mauersberger, B. Turner, C. Crawford, C. Brunt, and N. Kuno)

REFERENCES

1. Cunha, K., Smith, V. V., APJ 512 (1999) 1006.
2. Lubowich, D. A., Turner, B. E., Hobbs, L. M., APJ 508 (1998)729.
3. Schramm, D. N., and Turner, M. S., Rev. Mod. Physics 70 (1998) 303.
4. Lubowich, D. A., Pasachoff, J. M., Ostenson, J. A., E. Vangioni-Flam, R. Ferlet, and M. Lemoine (eds),Cosmic Evolution, World Scientific, 2001.
5. Lubowich, D. A.,Pasachoff, Jay M., Galloway, Robert P., Kurucz, R. L., Smith, Verne V., BAAS (1994) 26 1479.
6. Lubowich, D. A.,Pasachoff, Jay M., Balonek, Thomas J., Millar, T. J., Tremonti, Christy, Roberts, Helen, Galloway, Robert P., Nature (2000) 405 1025.