Determining the Galactic Deuterium Abundance

Eric Spaulding (Colgate University student visiting at Williams College)
and
Robert Galloway (Williams College)
Advisor: Jay Pasachoff, Williams College

The deuterium abundance D/H during the era of nucleosynthesis (the first 100 seconds) is a critical indicator of temperature and baryonic density in standard Big Bang models; in inflationary models it gives the abundance of dark matter. Since deuterium is not created in ordinary stellar processes, we can use current observations to determine primordial D/H. Our project seeks to determine a value for contemporary D/H by examining echelle spectra from early B stars and one halo star.

Introduction

A superdense kernel of all our universe's matter exploded outward and began its expansion, according to the standard "Big Bang" theory. From about 100 to 1000 seconds after this ferocious display all the protons, neutrons, and electrons are said to have combined into hydrogen, helium, and heavier isotopes such as deuterium as the matter expanded and cooled. The deuterium abundance is a sensitive indicator of the density of the universe during this period of nucleosynthesis (Walker et al. 1991). Deuterium nuclei fused with protons to form isotopes of helium, so the larger the amount of nucleons at the time of nucleosynthesis, the less deuterium would survive for us to observe. Because deuterium and other light elements, such as Li, Be, and B, are not believed to be created in normal stellar processes (Burbidge, Burbidge, Fowler, and Hoyle 1957), the presence of these elements is indicative of high-energy processes, like the "Big bang." We can therefore try to determine the primordial density of the universe by measuring how much deuterium exists today, assuming that there are no contemporary sources of deuterium. It is useful to know the deuterium abundance as a ratio of D/H (Pasachoff and Fowler 1974). By knowing both the density and rate of expansion of the universe, we can hope to determine if it is open or closed—if the universe will continue to expand resulting in the theorized "heat death of the universe," the consumption of all available energy due to increasing entropy (Levine 1988), or if the universe will slow its expansion and begin to collapse, only to explode again—the oscillatory model. Through observations astronomers are able to account for the "visible matter" that contributes to the overall density of the universe. By knowing the total density from the deuterium abundance, the amount of "dark" matter may then be calculated. Hence, the ultimate status and fate of the universe might be locked within the evasive isotope of deuterium.

Clearly the importance of the deuterium abundance is fantastic. If stars process material from D-rich to D-deficient, then we would expect that the amount of astration to be inversely proportional to the deuterium abundance, and the Galactic Center to be mostly devoid of any deuterium. Audouze et al. (1976) calculated a theoretical D/H ratio of 10^{10} in the galactic center due to such heavy processing. A local D/H of 1.6×10^{-5} (Linsky et al. 1993, McCullough 1992) was determined from UV D Lyman absorption spectra obtained with the Hubble Space Telescope.

A contending theory is that deuterium is produced through astration, and that D/H for the Galactic Center should be higher than for the less active disk. It is known that deuterium can be created in fusion reactions, or in spallation reactions, in which heavy nuclei such as He, C, N, and O are shattered by protons or alpha particles (Lubowich et al. 1993). Photodisintegration by gamma-rays can also occur, so some have suggested that deuterium might be created near black holes and other gamma sources (Lubowich et al. 1989). However, deuterium can only survive through rapid expansion and cooling, so some suspect that supernovae, of which there are statistically more in the Galactic Center than outside it, might be sources. Others prefer the notion that deuterium is primordial, but is attracted into the Galactic Center gravitationally—an "infall of nonastrated material" (Lubowich et al. 1993). If deuterium is created in the Galactic

Center to an appreciable degree, if we cannot tell what is primordial and what is not, then deuterium loses its value as a cosmological indicator.

So there are two goals. The first is qualitative: to determine the galactic abundance gradient to see if deuterium is created by stellar/galactic processes, and hence, if it is useful. The second is quantitative: to find a value for D/H, and to relate it to the baryonic density of the universe.

Most deuterium observations have been at less than 10% of the distance to the galactic center (Pasachoff and Vidal-Madjar, 1989). Penzias et al. (1977) attempted to measure the D/H value at several places in the Galaxy by measuring deuterated molecules in molecular clouds Sgr A and Sgr B2. Their efforts were repeated in 1993 by J. Pasachoff, D. Lubowich, C. Tremonti, T. Balonek and R. Galloway (Lubowich et al. 1993), who obtained a much higher S/N ratio by performing similar radio observations at Kitt Peak. That same year optical echelle spectra of slowly rotating B stars (Tau Herculis, Iota Herculis, and 67 Ophiuchi) were re-reduced, having been previously analyzed by W. Best, T. Ramond, and S. Sandys in the summer of 1992 (Best et al. 1992). Because boron had been detected, it was thought that these stars might harbor similarly sensitive atoms, like deuterium, in their upper atmospheres. During the summer of 1992, an upper limit of D/H = 10^{-5} was tentatively arrived at, based on the lack of a visible deuterium line. Unfortunately, a notable deuterium peak was not found in 1993, and it was discovered that some of the program stars were non-radial pulsators, causing the D-alpha line to be shifted near the atmospheric water line. It was hoped that analysis of Gamma Pegasi might yield better results, and so we analyzed it this year (the summer of 1994).

Observations

Observing runs during January and May of 1994 at Kitt Peak National Observatory were made by Don Lubowich, Jay Pasachoff, et al. to obtain echelle spectra with the coude feed spectrograph. Two of the stars which we tried reducing this summer were Gamma Pegasi, and Iota Herculis, are slowly rotating B stars that were analyzed in previous summers at Williams, and which were observed in hopes of achieving a higher signal-to-noise ratio than previously. Echelle spectra for a halo star, HD 140283, were also reduced to some degree. These stars were selected because sensitive elements such as boron had been observed in similar stars, elements whose sensitivities are similar to those of deuterium. The halo star seemed an especially promising candidate for deuterium for a number of reasons. First, it is not a radial pulsator, making spectral analysis easier, and second, Li, Be, and B had all been observed in this old star-- a low metallicity star which did not appear to astrate sensitive atoms like deuterium, but rather maintains them in its upper atmosphere.

Analysis of the echelle spectra for these stars involved the use of special reduction procedures. Images were zero-corrected, flat-corrected, and then apertures were extracted and wavelength-corrected using the IRAF procedure *doecslit.* Unfortunately, configuring *doecslit* and becoming familiar with the reduction process was very time consuming. Once it was configured, however, reducing spectra for the other stars up to that point was fairly quick. A D-alpha line was not seen in any of the images at this point. The telluric lines have yet to be removed from these spectra, so it is hard to determine a signal-to-noise ratio in order to even set an upper limit of D/H from these images. After the telluric lines are removed, fitting the data to theoretical models should be performed. It is likely that observations of halo stars will be continued in the future, at hopes of achieving a higher signal-to-noise ratio.

Acknowledgments

We would like to thank the following people for their assistance and support: Karen Kwitter, Barb Madden, Deborah Marazitti, Don Lubowich, Jay Pasachoff, Tom Balonek, George, and everyone else who facilitated things. Robert Galloway was supported by the Bronfman Science Center of Williams. Eric Spaulding was supported by a grant from the W. M. Keck foundation to the Keck Northeast Astronomy Consortium.

References

Audouze, J., Leequex, Reeves, H.,& Vigroux, L. 1976, ApJ, 208, L51

Best, W., Ramond, T., & Sandys, S. D. 1992, in Proceedings of the 1992 Symposium on Undergraduate Research in Astronomy,, ed. S. Boughn (Haverford College), 9

Burbidge, E. M., Burbidge, G. R., Fowler, W. A., & Hoyle, F. 1957, Rev. Mod. Phys., 29, 547

Levine, I. N., 1988, Physical Chemistry (New York: McGraw Hill), 103

Linsky, J., Brown, A., Gayley, K., Diplas, A., Savage, B. D., Ayres, T. R., Landsman, W., Shore, S. N., and Heap, S. R. 1993, ApJ., 402, 694

Lubowich, D. A., Anantharamaiah, K. R., & Pasachoff, J. M., 1989, ApJ. 345, 770

Lubowich, D. A., Pasachoff, J. M., Balonek, T. J., Tremonti, C. A., Galloway, R.P., & Mancuso, A. 1993, BAAS, 25,1467

McCullough, P. R. 1992, ApJ, 390, 213

Pasachoff, J. M., & Vidal-Madjar, A. 1989, Comments Astrophys., 14, 61

Pasachoff, J. M. & Fowler, W. A., 1974, Scientific American, 23, 108

Penzias, A. A., Wannier, P. G., Wilson, R. W., & Linke, R. A. 1977, ApJ. 211, 108

Walker, T. P., Steigman, G., Schramm, D. N., Olive, K. A., & Kang, H. S. 1991, ApJ, 376, 51