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Letter to the Editor

A New Upper Limit to the Abundance Ratio of Atomic Deuterium to Hydrogen in the Direction of the Galactic Centre

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SUMMARY. We report a new upper limit for the strength of the 327 MHz absorption line of deuterium in the direction of the galactic centre. Our observations do not confirm the possible detection of this line reported by Cesarsky et al (1973) and Pasachoff and Cesarsky (1974). We obtain an upper limit of 5.8×10^{-5} for the atomic D/H ratio by correlating the observed spectrum with the HI absorption spectrum of Sgr A. This limit is comparable to that of Weinreb (1962) of 8×10^{-5} for the direction of Cas A, and compatible with the direct measurement of the D/H ratio in nearby interstellar clouds from UV observations by the Copernicus satellite.

Key Words: Deuterium, Galactic Centre, Sgr A, Interstellar gas.

INTRODUCTION

The astrophysical importance of the deuterium to hydrogen abundance ratio, D/H, and the extremely high hydrogen optical depth towards the galactic centre have prompted several attempts in the past to detect the ground state hyperfine transition of deuterium at 327 MHz in this direction (see Cesarsky et al 1973). A possible detection of this line in absorption towards the galactic centre and a further compatible observation have been reported by Cesarsky et al (1973) and Pasachoff and Cesarsky (1974). However, recent observations of Sarma and Mohanty (1978) do not show any positive detection.

We report in this note a further attempt to detect this line in the same direction using the Ooty Radio Telescope described by Swarup et al (1971).

OBSERVATIONS AND ANALYSIS

The 530 m x 30 m Ooty Radio Telescope operates at a nominal centre frequency of 326.5 MHz and has an HPBW of 5.6 cos δ arcmin in the north-south and 2° in the east-west direction in the total power mode of operation. With the new RF amplifiers, installed recently, the system temperature is now about 250°K when the antenna is pointed towards a cold region in the sky. The observations were carried out using a 36-channel filter bank receiver as the back-end, having a 2.5 KHz (2.3 km s^{-1}) filter bandwidth and 3 KHz (2.7 km s^{-1}) filter separation. A frequency synthesizer operated from a rubidium frequency standard was used as the first local oscillator.

Observations were made during two major observing sessions in June 1978 and July 1978 totalling about 84 hours of data. Interference was noticed in only a few records and these were rejected. During the initial observations, simple frequency switching was employed in which the first local oscillator was switched every 200 ms between an on-line frequency (ON) and a reference frequency 120 KHz away. This resulted in a baseline slope which is natural to any phased array because of the slight beam shift produced when the frequency of the first local oscillator is altered. To minimise this slope during the subsequent observations, data was acquired in a double frequency switched mode; the first local oscillator was switched between an on-line frequency and two reference frequencies (REF1, REF2) on either side of the on-line frequency in the sequence ON-REF1-ON-REF2-ON- etc., spending 200 ms on each frequency. LSR corrections were applied as necessary to keep the 0 km s^{-1} velocity channel for the deuterium line located at the centre of the filter bank.

Data was acquired only while tracking the region Sgr A ($\alpha = 17^h42^m30^s$, $\delta = -28$ 59' (1950)) over an hour angle range generally between -3^h30^m and 5^h0^m. Each individual day's data was analysed to obtain the spectrum for that day. These one-day spectra were averaged with weighting factors proportional to their integration time. A linear baseline with a slope of 0.19×10^{-4}(km $s^{-1})^{-1}$ was fitted to the outer 12 channels of the averaged spectrum to get the final integrated spectrum shown in Fig. 1. The total integration time for this spectrum is 2.737×10^5s.

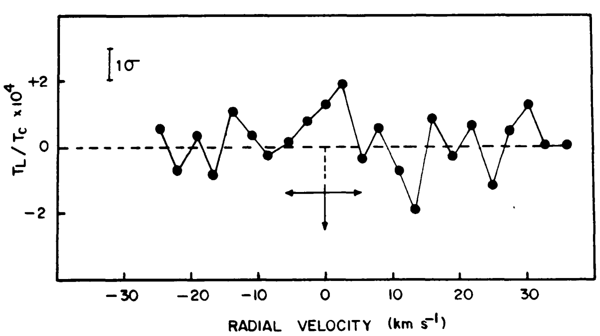

Fig. 1. Spectrum in the direction of Sgr A at the frequency of the deuterium line. The filter bandwidth was 2.3 km s^{-1} and the ordinate is in units of optical depth. The position and full width at half optical depth of the HI absorption component used for the correlation (see text) is also indicated.

INTERPRETATION OF THE OBSERVATIONS AND DISCUSSION

We have plotted in the ordinate of Fig. 1 the antenna temperature in the line (T_L) divided by the antenna temperature due to the continuum background

Send offprint requests to: V. Radhakrishnan source (T_C). The points in the plot of Fig. 1 show an rms fluctuation of 0.93×10^{-4} as against the theoretically estimated value of 1.04×10^{-4} expected in the absence of any spectral line. No feature above 2.5σ is seen in the spectrum. This implies an upper limit of 2.3×10^{-4} (2.5σ) for T_L/T_C for the deuterium line, in the direction of the galactic centre.

In view of the number of references in the literature for the abundance ratio D/H in the direction of the galactic centre, we compare our observations with those of Cesarsky et al (1973) and Sarma and Mohanty (1978). In their analysis Cesarsky et al (1973) use the relation $\tau_D = -T_L/fT_C$ where 'a fraction f of the observed continuum radiation originates behind an absorbing cloud of optical depth τ_D in the deuterium line and τ_H in the hydrogen line'. We show in Fig. 2a and Fig. 2b the spectra reported by Pasachoff and Cesarsky (1974) and Sarma and Mohanty (1978). In Fig. 2c we show our spectrum smoothed to the same resolution (4.5 km s^{-1}) and with T_L/fT_C plotted in the ordinate for comparison purposes. The value of f for Fig. 2a is 0.4 and for Fig. 2b and Fig. 2c is 0.77 (instead of 0.56 used by Sarma and Mohanty (1978); they used fT_S instead of fT_C in their plots). As can be seen from the figure, we do not find any evidence in our spectrum for the dip at -4 km s^{-1} seen in the spectrum of Pasachoff and Cesarsky (1974).

To estimate an upper limit to the abundance ratio D/H, of deuterium to hydrogen, we assume, in the

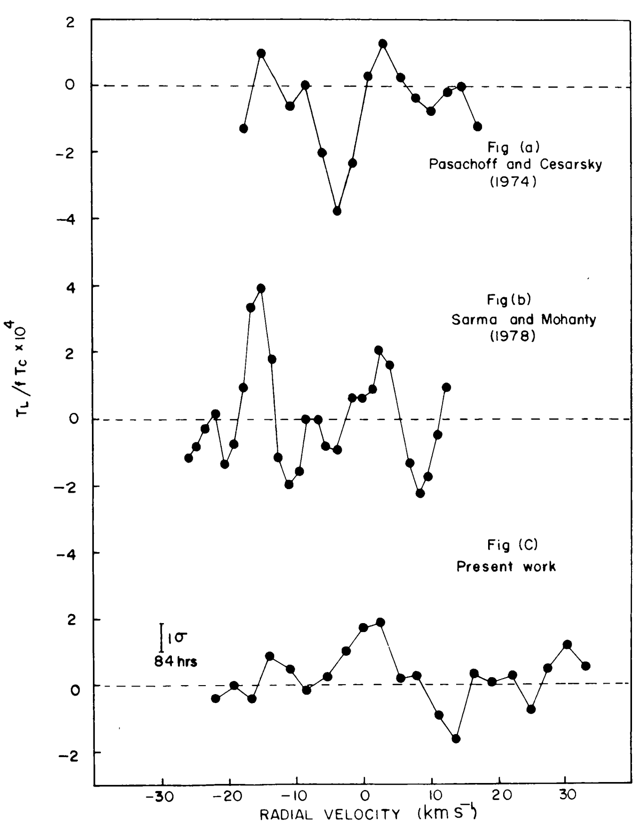

Fig. 2. A comparison of various observations in the direction of Sgr A at the deuterium line frequency. The observations reported in this paper are shown in Fig. 2c smoothed to the same resolution (4.5 km s^{-1}) as reported for the observations in 2a and 2b. The ordinates were also chosen to make the observations directly comparable as explained in the text.

absence of any positive detection of the deuterium line, that whatever deuterium is present in the interstellar gas between us and the galactic centre is distributed in the same way as neutral atomic hydrogen. A knowledge of the optical depth in the 21 cm hydrogen line, in this direction to the required accuracy was hitherto lacking. However, a recent analysis by Radhakrishnan and Sarma (1979) of an interferometer measurement obtained with the Parkes Interferometer (Radhakrishnan et al, 1972) has provided a very reliable estimate of the parameters of the 21 cm absorption components in the spectrum of Sgr A. The high S/N ratio in the wings of the deep central feature was used to determine its peak optical depth of 4.3, its mean velocity of -0.2 km s^{-1} and a full width at half maximum optical depth of 11.8 km s^{-1}.

In our analysis we further assume that the optical depth due to hydrogen over such a long path length in the plane is, to first order, independent of the direction. This assumption is based on the statistical study of Radhakrishnan and Goss (1972) in which they conclude that neutral hydrogen appears in cloud concentrations, of which there are at least 2.5 per kpc in any line of sight along the plane. The above assumption, therefore, is likely to cause errors only as a result of differential galactic rotation altering the shape of the hydrogen absorption profile, whose area however, should depend on the distance only. We have estimated the magnitude of possible lowering of the peak optical depth over the angle of the continuum source, taking account of the decrease in intensity of the continuum radiation away from the central peak. We find this effect to be negligible and correspondingly analyse our results on the assumption that the parameters of the 21 cm absorption profile that would be obtained with the antenna beam of the Ooty telescope would be essentially the same as found from the Parkes measurement referred to above. To estimate the optical depth in the deuterium line we have used the simple relation $\tau_D = -T_L/T_C$, and to estimate an upper limit for D/H a value of 4.3 for the 21 cm hydrogen optical depth. The appropriateness of this value of 21 cm optical depth for the present purpose has been discussed by Radhakrishnan and Sarma (1979).

From the above assumptions it follows that in our spectrum of Fig. 1, the deuterium profile, if present, should resemble the hydrogen profile discussed above. The velocity width of the deuterium profile should be same as that of the hydrogen profile since the broadening of the latter must clearly be due to the external motions of the large number of clouds along the line of sight; the line widths of individual clouds are much smaller as determined from studies in other directions of the galaxy.

We have accordingly correlated the deuterium spectrum shown in Fig. 1 with the 11.8 km s^{-1} wide component centred at -0.2 km s^{-1} in the HI absorption spectrum. This component was least-square fitted to the deuterium spectrum by varying its peak optical depth.

The best fit was obtained for a peak optical depth of $(-2.3 \pm 3.0) \times 10^{-4}$. The errors quoted are the 95% confidence limits from a Chi-square goodness-of-fit test and indicate an upper limit for the deuterium optical depth of 0.7×10^{-4}; using the value for $\tau_H = 4.3$ referred to earlier, we get an upper limit for the ratio of the optical depths τ_D/τ_H of 1.6×10^{-5}.

The relationship between the ratio of optical depths in the deuterium and hydrogen lines and the ratio of their column densities has been discussed by Weinreb (1962), who showed that $\tau_D/\tau_H = 0.33 x N_D/N_H$ on the assumption that half of the doppler broadened width of the lines arises due to thermal motions. We have shown above that thermal broadening must contribute negligibly to the line widths in this case, and the appropriate relation becomes $\tau_D/\tau_H = 0.28 x N_D/N_H$. Using this we get the 95% confidence upper limit for the mean abundance ratio of atomic deuterium to hydrogen in the interstellar gas between us and the galactic centre as 5.8×10^{-5}.

COMPARISON WITH OTHER OBSERVATIONS AND CONCLUSIONS

Our upper limit is comparable to the upper limit of 8×10^{-5} obtained by Weinreb (1962) in a notable attempt to measure this line in the direction of Cas A. Direct and unambiguous determination of the atomic deuterium to hydrogen ratio in nearby interstellar space has been made with the Copernicus satellite by observing the Lyman absorption lines of atomic D and H in the direction of several stars ranging in distance between 1 and 1,000 parsecs (York and Rogerson 1976, Vidal-Madjar et al 1977, Dupree et al 1977). In the 9 directions for which these lines are observed, the abundance ratio D/H has an unexpected scatter with values ranging from 2×10^{-6} to 4×10^{-5} and a mean value around 2×10^{-5}. These results seem to indicate that even if the highest D/H ratio observed by Copernicus were typical of all the clouds along the 10 kpc pathlength between us and the galactic centre, we would still have failed to detect the line.

If we assume that the clouds observed by Copernicus are typical of those found in the direction to the galactic centre, we should expect a D/H ratio of the mean value referred to above, namely 2×10^{-5}. The unambiguous detection in the 327 MHz absorption line of a value one third of our upper limit would require an increase in observing time of at least an order of magnitude over the 84 hours taken for the present observation. As the continuum radiation from the source Sgr A dominates system noise for most large radio telescopes no improvement can be expected with even larger collecting areas. It also appears that unless the atomic D/H ratio were anomalously higher in certain clouds, by over an order of magnitude, it would be even more difficult to detect this line in absorption against continuum sources in other directions where differential galactic rotation would contribute to reducing the value of the peak optical depth.

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