Mon. Not. R. astr. Soc. (1978) **184**, 181–184

Search for the deuterium absorption line at 327 MHz in the direction of the Galactic Centre

N. V. G. Sarma *Radio Astronomy Centre, TIFR, PO Box 8, Ootacamund-643 001, India, and Raman Research Institute, Hebbal PO, Bangalore-560 006, India*

D. K. Mohanty *Radio Astronomy Centre, Ootacamund-643 001, India*

Received 1977 December 14; in original form 1977 September 23

Summary. A search for deuterium line-absorption at 327 MHz towards Sgr A was made for a total of 105 hr. This has yielded an upper limit of 2.7×10^{-4} for the deuterium to hydrogen abundance ratio in the intervening medium. This upper limit lies within the range reported by Pasachoff & Cesarsky.

Introduction

Determination of the deuterium to hydrogen abundance ratio, D/H, in the Universe is considered very important because of its astrophysical significance in placing strong constraints on cosmological parameters. Several attempts have been made in the past to detect the ground-state hyperfine transition of deuterium at 327 MHz in our Galaxy (see Cesarsky, Moffet & Pasachoff 1973 for a review). The most sensitive of these observations gave an upper limit of 8×10^{-5} for D/H in the direction of Cas A (Weinreb 1962). The positive detection of DCN (Jefferts, Penzias & Wilson 1973) in the Orion cloud at mm-wavelengths led to the determination of the DCN to HCN ratio as 3×10^{-3} which is about 100 times more than the estimated D/H ratio (Geiss & Reeves 1972) for protosolar gas. This excess was interpreted as a possible consequence of chemical fractionation (Solomon & Woolf 1973), but its nature and extent is not well understood. Hence, a derivation of the D/H ratio from the above observations involves considerable uncertainties.

Possible detection of the 327-MHz deuterium absorption-line towards the Galactic Centre was reported by Cesarky, Moffet & Pasachoff (1973) and by Pasachoff & Cesarsky (1974). For the D/H ratio, they gave an upper limit of 3.5×10^{-4} and a range from 3.5×10^{-4} to 2×10^{-5} depending upon the uncertainties in the assumed values for beam-filling factor and the optical depth in the 21-cm hydrogen line in the direction of Sgr A. The most accurate and direct determination of the D/H ratio has been made from the *Copernicus* satellite by studying the deuterium and hydrogen Lyman lines in the line of sight to five stars and yields a value of 1.8×10^{-5} (York & Rogerson 1976). However, this value may only be representative of the region within about 200 pc of the Sun and further, the method cannot be easily extended to distant regions of our Galaxy.

Recent survey observations of the ratio DCN/HCN in many directions (Penzias *et al.* 1977) have indicated that the ratio remains essentially uniform (ranging between 2 and

5×10^{-3}) over large regions of our Galaxy, except in the direction of Sgr B where it is much lower. Still, in view of the existing uncertainties about the process of formation and enrichment of these molecules, observations of the deuterium line at the frequency of 327 MHz are very desirable in order to obtain a direct estimate (or limits) of the D/H ratio for different parts of our Galaxy.

In this note we report an attempt to detect deuterium line-absorption towards the Galactic Centre, using the Ooty radio telescope (Swarup *et al.* 1971) which operates at a nominal central frequency of 326.5 MHz. The results are compared with the earlier estimates of Pasachoff & Cesarsky (1974).

Observations and analysis

The Ooty radio telescope (ORT) has a resolution of $5.6/\cos\delta$ arcmin in the north–south and 2° in the east–west directions in the total-power mode of operation. Its system temperature is about 350 K when the antenna is pointed towards a cold region of the sky. For deuterium line-observations, a 40-channel filter-bank receiver with 2.5 kHz filter bandwidth (2.3 km/s) and 1.5 kHz filter separation was used as the back-end. A second converter was used to convert the IF spectrum of the ORT receiver system from 30 MHz to the 18-MHz input frequency of the filter-bank receiver.

Observations towards the Galactic Centre were performed during three observing sessions in 1975 November, 1976 April and July logging a total of more than 105 hr of data. Interference was seen in only a few records and these were rejected. Data were acquired in a frequency-switched mode (the second local-oscillator frequency being varied by 60 kHz) with on- and off-line observations lasting 200 ms each. Of the 40 filter channels, the total power outputs of 36 channels were sampled every 5 ms by computer control and the average of each channel for the 200 ms switching period was stored separately. During each observing session of 6–10 day, LSR corrections were applied as necessary to the second local-oscillator frequency so as to ensure that the deuterium line fell approximately in the middle of the filter bank.

The observations consisted of acquiring data while alternately tracking, for half an hour each, the source Sgr A and a reference region lying about 9 arcdeg east of Sgr A. Thus the on- and off-source observations were carried out at approximately the same hour angle. During the on-source observations, a broadband attenuator was introduced in the common 30-MHz IF chain in order to make the total-power outputs of the filter channels nearly the same as during the off-source observations.

In the final stage of the analysis, each on-source observation was combined with the immediately following off-source observation. The mean ratio of off-line total-power outputs obtained during the on- and off-source observing periods was found and this average factor was used to normalize the observations. Then, the difference spectrum ((on-line) – (off-line)) for both on- and off-source was obtained. The difference spectrum for off-source was then subtracted from the difference spectrum for on-source. The mean spectrum was obtained after combining all the 1-hr spectra with appropriate channel off-sets depending upon the corrections to the local standard of rest. From the mean spectrum, a linear baseline (least-squares fit) slope of 0.03 K/(km/s) was subtracted to derive the final spectrum, which is shown in Fig. 1(a).

Results and discussion

The total observing time of 105 hr was equally distributed between on- and off-source observations. The system temperatures when the antenna was pointed towards the reference

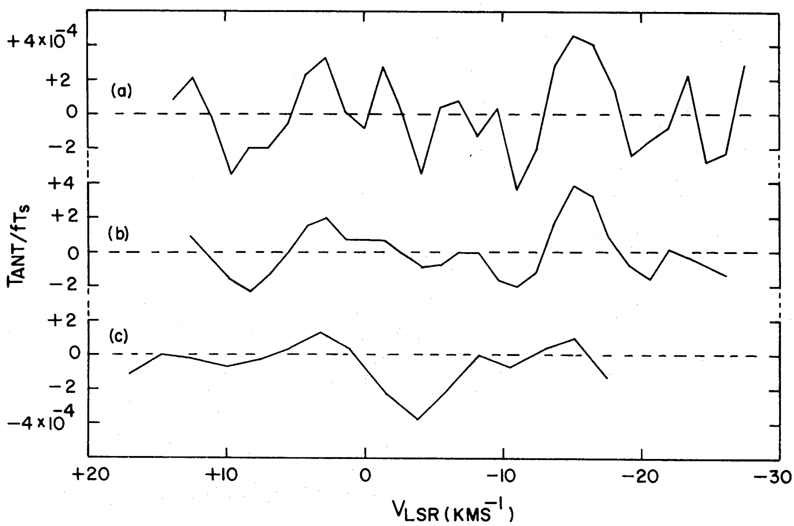

Figure 1. Spectra at the 327-MHz deuterium line frequency. (a) Spectrum obtained with a resolution of 2.3 km/s. (b) Spectrum of Fig. 1(a) smoothed to a resolution of 4.5 km/s. (c) Spectrum published by Pasachoff & Cesarsky (1974). The ordinates for all three figures have been normalized to be comparable. See text.

region (off-source) and towards Sgr A were estimated to be 440 ± 30 and 1350 ± 100 K respectively. The latter value was used for normalizing the day to day total-power output counts. Following Cesarsky *et al.* we assume the diameter of the absorbing cloud to be 30 arcmin. We have used the 408-MHz continuum map of the Galactic Centre region (Little 1974) for estimating the brightness temperature of the background emission. The antenna temperature contribution due to the corresponding background source of size 30 × 6 arcmin in the ORT beam is estimated to be 750 K. This gives a value of 0.56 for the beam filling factor, f, as defined by Cesarsky *et al.* (1973). The ordinate of Fig. 1(a) showing the final observed spectrum, is the antenna temperature in the line normalized by the antenna temperature due to the 30 × 6 arcmin continuum background source as deduced above. This enables a comparison between our results and those reported by Pasachoff & Cesarsky (1974).

Our spectrum (Fig. 1(a)) has a velocity resolution of 2.3 km/s. This spectrum, smoothed to a resolution of 4.5 km/s, is shown in Fig. 1(b) and the average spectrum published by Pasachoff & Cesarsky with nearly the same resolution in Fig. 1(c). The ordinate for Fig. 1(c) is based on the values of 0.4 for the beam-filling factor and 1500 K for T_S. It may be noted that the peak to peak fluctuations are nearly the same to within 15 per cent for the two profiles in Fig. 1(b) and (c). This was further verified by comparing the rms of our pre-smoothed data of Fig. 1(a) with the rms of the fine-resolution data over the full range as published by Cesarsky *et al.* (1973) and by Pasachoff & Cesarsky (1974).

The feature at −4 km/s in Fig. 1(c) is significant at the level of 3σ (Pasachoff & Cesarsky 1974). However, this feature is not seen in our spectrum of Fig. 1(b) for which the rms noise is estimated as 1.6×10^{-4} (1σ). The absence of any peak above 2.5σ puts an upper limit of 4.0×10^{-4} for the normalized antenna temperature. Using this value, it is possible to obtain an upper limit for the D/H abundance ratio, provided that the optical depth in the 21-cm hydrogen line in the direction of Sgr A is known.

Due to limitations on sensitivity and possible emission structure in the absorption profile, no accurate value for the peak optical-depth of H I towards Sgr A has been available in the literature. Nevertheless, it is possible to estimate this value fairly reliably by combining the available data on hydrogen clouds in the galactic plane (Radhakrishnan & Goss 1972) with the data on hydrogen-line absorption towards Sgr A (Radhakrishnan *et al.* 1972). Such an analysis (in preparation) leads to a value of 4.6 ± 0.3 for the peak optical depth for the zero velocity feature of the H I absorption spectrum towards Sgr A. Taking this value for the hydrogen optical depth, we deduce that the D/H abundance ratio towards Sgr A is less than 2.7×10^{-4}. This upper limit lies within the range reported by Pasachoff & Cesarsky (1974).

Assuming that the observed galactic deuterium is primordial in origin, Wagoner (1973) and Gott *et al.* (1974) have investigated the constraints imposed on the cosmological parameters such as the density of the Universe and the deceleration parameter. According to their calculations, our present upper limit on the D/H ratio, as also the range for the ratio given by Pasachoff & Cesarsky (1974), would lead to the conclusion that the derived cosmic densities are insufficient to close the Universe.

Acknowledgments

We thank Mr A. J. Selvanayagam for constructing and testing the filter-bank receiver and Mr N. A. Rajagopalan for his help in data analysis. We are indebted to Professors G. Swarup and V. Radhakrishnan for their continued interest and many helpful discussions.

We also thank the referee who pointed out an error in our earlier estimate of hydrogen optical-depth towards Sgr A.

References

Cesarsky, D. A., Moffet, A. T. & Pasachoff, J. M., 1973. *Astrophys. J.*, **180**, L1.
Geiss, J. & Reeves, H., 1972. *Astr. Astrophys.*, **18**, 126.
Gott, J. R., Gunn, J. E., Schramm, D. N. & Tinsley, B. M., 1974. *Astrophys. J.*, **194**, 543.
Jefferts, K. B., Penzias, A. A. & Wilson, R. W., 1973. *Astrophys. J.*, **179**, L57.
Little, A. G., 1974. *IAU Symp. 60*, p. 491, eds Kerr, F. J. & Simonson, S. C., D. Reidel, Dordrecht, Holland.
Pasachoff, J. M. & Cesarsky, D. A., 1974. *Astrophys. J.*, **193**, 65.
Penzias, A. A., Wannier, P. G., Wilson, R. W. & Linke, R. A., 1977. *Astrophys. J.*, **211**, 108.
Radhakrishnan, V., Goss, W. M., Murray, J. D. & Brooks, J. W., 1972. *Astrophys. J. Suppl.*, **24**, 49.
Radhakrishnan, V. & Goss, W. M., 1972. *Astrophys. J. Suppl.*, **24**, 161.
Solomon, P. M. & Woolf, N. J., 1973. *Astrophys. J.*, **180**, L89.
Swarup, G., Sarma, N. V. G., Joshi, M. N., Kapahi, V. K., Bagri, D. S., Damle, S. H., Ananthakrishnan, S., Balasubramanian, V., Bhave, S. S. & Sinha, R. P., 1971. *Nature, Phys. Sci.*, **230**, 185.
Wagoner, R. V., 1973. *Astrophys. J.*, **179**, 343.
Weinreb, S., 1962. *Nature*, **195**, 367.
York, D. G. & Rogerson, J. B., 1976. *Astrophys. J.*, **203**, 378.