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Research Note

H I Absorption in the Direction of the Galactic Centre

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Summary. A gaussian analysis of the H I absorption spectrum of Sgr A obtained with the Parkes Interferometer has yielded the following results. The optical depth at zero velocity has contributions from both a narrow deep feature, and an unexpected, very wide, low optical-depth feature. The peak optical depths for these two components are 4.3 and 0.3 respectively. The width of the former feature, identified with conventional cold concentrations, leads to a new determination for the external motions of interstellar clouds of $\sigma = 4.8\,\mathrm{km\,s^{-1}}$. The new wide feature represents an amount of neutral hydrogen comparable to that in standard cold concentrations and contains most of the energy in mass motions of the interstellar gas. Neglecting its contribution, the amount of hydrogen seen in absorption towards Sgr A is in close agreement with that expected from studies in other directions in the galactic plane. Both the above components have mean velocities differing from zero by less than $0.25\,\mathrm{km\,s^{-1}}$, thus confirming the standard value of the solar motion and contradicting galactic models which postulate a radial motion of the local standard of rest.

Key words: H I absorption – galactic centre – optical depth – cloud motions

Introduction

The Galactic centre source Sgr A was one of the many galactic objects observed for 21 cm absorption in the Parkes Survey carried out by Radhakrishnan et al. (1972). Most of the absorption spectra obtained in this survey were analysed in terms of gaussian components whose parameters were then used to derive the statistical properties of the interstellar hydrogen (Radhakrishnan and Goss, 1972). In the case of Sgr A (Fig. 19, p. 77 of the Parkes Survey) no such analysis was carried out, primarily because of the very high (and consequently very inaccurate) optical depth at the centre of the dominant zero velocity feature in the spectrum.

Recent attempts to measure the 327 MHz deuterium line in absorption against Sgr A (Cesarsky et al., 1973; Sarma and Mohanty, 1978; Anantharamaiah and Radhakrishnan, 1979) provided an impetus to assess as accurately as possible the neutral hydrogen optical depth in the direction of this source; the deuterium optical depth – or upper limit to it – cannot be interpreted in terms of a deuterium to hydrogen abundance ratio without a knowledge of the hydrogen optical depth. An analysis was therefore undertaken of the interferometric absorption profile obtained in the Parkes Survey referred to above, and we present here a number of interesting results obtained from this spectrum.

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Gaussian Analysis

An examination of the interferometer profile indicated that while those measurements close to zero velocity were unreliable because of the poor signal-to-noise ratio, the spectrum should be quite accurate for values of optical depth less than 2. Figure 1a shows the spectrum – after deletion of the inaccurate values-obtained with filters of bandwidth $2\,\mathrm{km\,s^{-1}}$. This large spread in radial velocity (almost $300\,\mathrm{km\,s^{-1}}$) in a direction free in principle of galactic rotation effects, has been attributed to non-circular motions in the inner part of the galaxy and has received considerable attention in the literature.

A gaussian fitting analysis of this spectrum showed that 8 components were required for a satisfactory fit. The parameters of these components are given in Table 1, and Figs. 1b–g illustrate how they contribute to making up the total spectrum. Six of the 8 components have mean velocities clearly different from zero and they are shown in Fig. 1b. The result of subtracting them from Fig. 1a is shown in Fig. 1c. An examination of Fig. 1c makes it immediately clear why the remaining optical depth cannot possibly be accounted for by a single gaussian centred at zero velocity. The signal-to-noise ratio is high in the wings of the deep feature, and the best fit gaussian to these wings is represented in Fig. 1d. Subtraction of this component from Fig. 1c leaves the

Table 1. Parameters of the gaussian components fitted to the H I absorption spectrum of Sgr A

Fig. no.	Velocity $\mathrm{km\,s^{-1}}$	Peak τ	σ $\mathrm{km\,s^{-1}}$	N_H/T_s $10^{19}\,\mathrm{cm^{-2}\,K^{-1}}$
1b	−134.5	0.09	4.0	0.17
1b	− 53.3	1.1	2.5	1.20
1b	− 32.0	0.24	1.5	0.17
1b	+ 14.3	0.91	1.5	0.64
1b	+ 22.3	0.29	3.0	0.39
1b	+ 48.5	0.45	9.0	1.84
1d	−0.23±0.06	4.3±0.2	5.0±0.1	9.8
1f	− 0.22	0.3	35.0	4.9

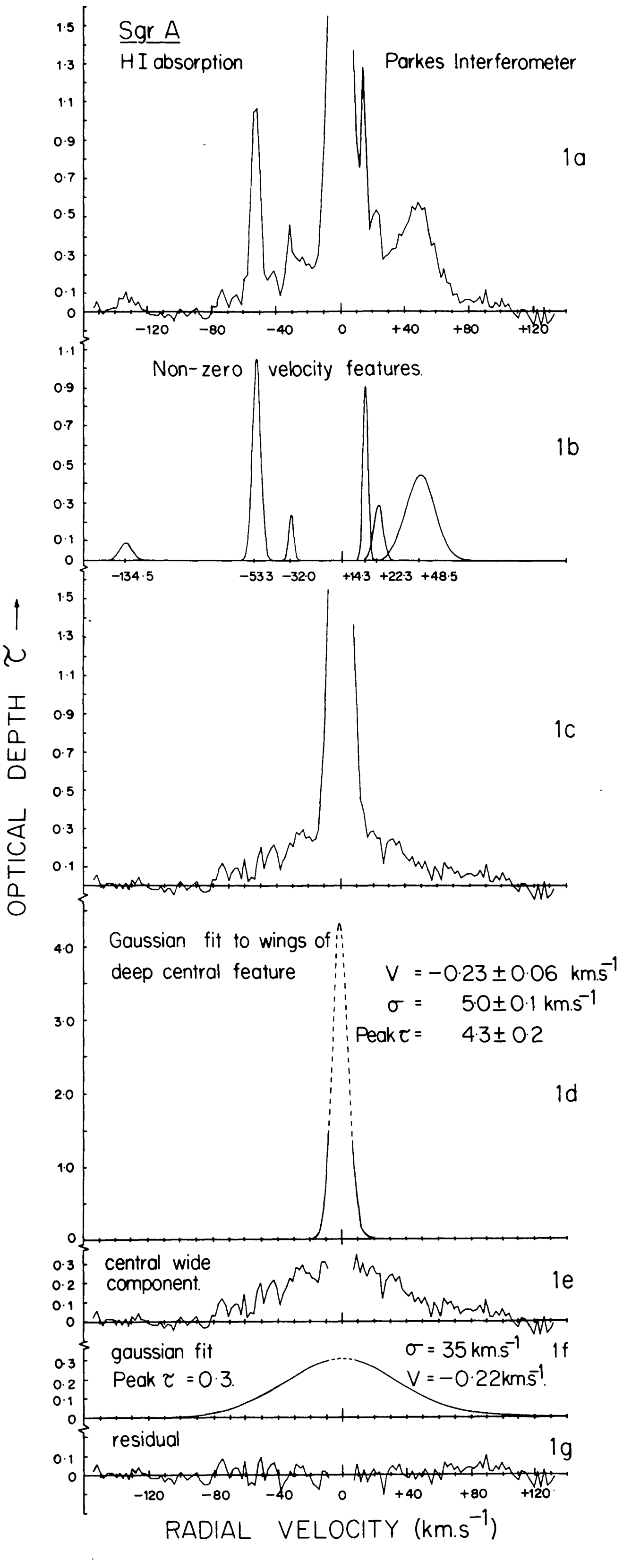

Fig. 1a–g. Resolution of the H I absorption spectrum of Sgr A **a**, into 8 gaussians **b, d,** and **f,** and the residuals **c, e,** and **g,** after progressive subtraction of these components

central wide component shown in Fig. 1e. This wholly unexpected feature is extremely wide by the standards of 21 cm absorption features and can be approximated by the gaussian illustrated in Fig. 1f. The residuals after subtracting it are shown in Fig. 1g.

Discussion

In discussing the 8 gaussian components fitted to the absorption spectrum of Sgr A we shall group them into 3 categories.

1. The six non-zero velocity features of Fig. 1b.
2. The deep zero velocity feature of Fig. 1d.
3. The new wide component of Fig. 1f.

We begin by noting that the peak optical depth and velocity width of 5 out of the 6 features in Fig. 1b are similar to those observed in the spectra of other sources. Judging only on the basis of the parameters of the gaussians, they could well represent concentrations of cold hydrogen such as those found in other directions and which have been discussed by Radhakrishnan and Goss (1972). Their common characteristic is that they have anomalous radial velocities and probably originate in a region where non-circular motions are prevalent. All of these features, or their emission counterparts, have been associated with particular phenomena for which a variety of models have been proposed in the literature; see for example, Sanders and Wrixon (1973), Oort (1974), Schwarz et al. (1977), and Burton and Liszt (1978). The various models may differ from each other on the precise locations, motions, origin, etc. of the gas giving rise to these features, but all authors seem to be in agreement that the arena is the region within 3–4 kpc of the centre of the galaxy.

The deep central feature (Fig. 1d) is characterised by a very high optical depth and a velocity width somewhat greater than is typical for standard concentrations. The justification for fitting a gaussian to the wings of Fig. 1c is that it is what one would expect from the superposition of a large number of typical concentrations located along the line of sight for which the radial velocity component due to galactic rotation was zero. In fact, the mean velocity of the fitted gaussian ($-0.23 \pm 0.06\,\mathrm{km\,s^{-1}}$) differs from zero by less than the accuracy to which the component of solar motion in the direction of the Galactic centre is known with certainty. The width of this feature ($\sigma = 5.0\,\mathrm{km\,s^{-1}}$) should therefore truly represent the "external motions" (van Woerden, 1967) of interstellar clouds, as the average internal motions are much smaller, typically $\sigma_{\mathrm{int}} \approx 1.5\,\mathrm{km\,s^{-1}}$. The concentrations responsible for this feature are presumably those within 6–7 kpc of the sun, and outside of the inner region close to the Galactic centre. If so, it may be noted that the one-dimensional value for the external motions obtained here ($\sigma_{\mathrm{ext}} = 4.8 \pm 0.2\,\mathrm{km\,s^{-1}}$) refers to the single longest line of sight where galactic rotation effects are negligible. Most previous estimates were obtained from shorter lines of sight at intermediate and high galactic latitudes and have been discussed recently by Crovisier (1978); a recent determination by him, also from 21 cm absorption measurements, yields a value of $5.7 \pm 0.9\,\mathrm{km\,s^{-1}}$.

An independent handle to assess the validity of the above picture is the measured area under the absorption features. From observations of cold dense hydrogen over a path length totalling 161 kpc in the galactic plane, Radhakrishnan and Goss (1972) derived a value of $N_{\mathrm{H}}/T_s = 1.44\ 10^{19}\,\mathrm{cm^{-2}\,K^{-1}}$ per kpc for the area under H I absorption features. The values of N_{H}/T_s for each of the components in the Sgr A profile have been tabulated in the last column of Table 1. The total for the 7 features in categories 1 and 2 (Fig. 1b and d) is $14.2\ 10^{19}$, corresponding almost exactly to an effective path length of 10 kpc. While this remarkable agreement may be considered fortuitous, it must be noted such a comparison is possible only in this unique direction where, by definition, we know the distance to the source exactly. Any change in the galactic distance scale will therefore leave this agreement unaffected.

The values of N_H/T_s for categories 1 and 2 taken separately lead to equivalent path lengths of 3.1 kpc and 6.8 kpc. These numbers may be considered an even greater coincidence, or an affirmation of the reliability of the statistically derived value, depending on one's point of view. We believe, in any case, that they add weight to the totally independent determination of the optical depth of the zero velocity feature of Fig. 1d; they also support a picture in which the amount of cold neutral hydrogen in the inner part of the galaxy is not too different from elsewhere in the galactic plane, although the motions may be very peculiar.

The peak optical depth in the 21 cm line at zero velocity is approximately 4.6, of which quantity 4.3 is contributed by the deep and relatively narrow component, and 0.3 by the wide feature. As can be seen in Fig. 1a, the excess optical depth at zero velocity over a baseline of $\pm 30\,\mathrm{km\,s^{-1}}$ will only be that due to the narrow feature, ~ 4.3; this is therefore the appropriate number to be used in comparing deuterium optical depth limits in this direction when the total baseline for the measurement is of the order indicated above.

We turn now to low wide absorption feature of Fig. 1e. A reasonable approximation of its characteristics is the gaussian shown in Fig. 1f with a peak optical depth of 0.3, a mean velocity of $-0.22\,\mathrm{km\,s^{-1}}$, and a dispersion of $35\,\mathrm{km\,s^{-1}}$. The extraordinary width of this feature would correspond to a temperature of $1.5\,10^5$ K for pure thermal broadening, if one could imagine hydrogen to remain neutral at such a temperature; the width is clearly due to mass motions, and the gas is in a highly agitated state. It is unlikely that these motions are due to turbulence in a single isolated concentration with a mean velocity indistinguishably different from that of the feature of Fig. 1d. We conclude that we are observing the combined effect of many very shallow features – almost a diffuse medium – distributed over a long path length where the absence of differential galactic rotation enables the peak to build up to the observed value of 0.3.

In other directions in the plane, it would be difficult to detect this component because of the spreading out in velocity, and blending with other features in the same velocity range. It appears that we are seeing a component of the interstellar medium which has an optical depth of $\leqq 0.005$ per 100 pc which would be the order of the path length when observing at intermediate or high galactic latitudes. If this component were present in the solar neighbourhood, its detection in absorption in directions away from the plane would require a sensitivity which was well beyond the limits of the Parkes Survey.

An estimate of the spin temperature of this gas can be obtained by combining the emission measurements made with a single dish in the direction of the galactic centre with the optical depth information obtained in this work. Antenna temperatures obtained with the Bonn 100 m telescope (Sanders et al., 1977) at velocities where the optical depth contribution to the profile of Fig. 1a is mainly from the wide component of Fig. 1f, combined with the optical depths of this component at these velocities leads to an estimate for the spin temperature of this gas of a few hundred kelvins. As the area under the curve ($N_H/T_s = 4.9\,10^{19}$) is half that of the area under the deep central feature (Table 1) it is clear that the amount of hydrogen in this disturbed state is greater than that in typical concentrations which have a much lower spin temperature. It thus appears to form the major component of the interstellar neutral hydrogen, at least in the galactic plane. As it also represents the major reservoir of energy in mass motions of the interstellar gas, we believe that this highly agitated low-optical-depth gas is hydrogen inside the shock fronts of supernova remnants along the line of sight to the source. Detailed arguments supporting this hypothesis will be presented in a subsequent communication (Radhakrishnan and Srinivasan, in preparation).

Finally, the close agreement in the mean velocities of the central components of Fig. 1d and f (both being practically equal to zero) enables one to make some remarks on galactic models. It was suggested for example from a study of H I emission profiles (Kerr, 1961) that the local standard of rest could have a net radial outward motion of approximately $7\,\mathrm{km\,s^{-1}}$. On the other hand, it was pointed out by Clark (1965) that the mean velocity of the central feature in the Sgr A absorption profile agrees well with the local standard of rest. When the gas is optically thick, as in this direction at low velocities, emission measurements are weighted preferentially by the nearby gas whereas absorption measurements truly add the optical depths all along the line of sight. The somewhat improved determination in the present work, coupled with its agreement with the mean velocity of the new wide component would conflict with any galactic model requiring a net radial motion (inward or outward) of the local standard of rest greater than a fraction of a $\mathrm{km\,s^{-1}}$. If the local standard of rest were postulated to have a radial motion of several $\mathrm{km\,s^{-1}}$, the present analysis would force one to the embarassing conclusion that all of the H I gas in the line of sight to the centre (outside the inner region) also shares precisely in this mean motion.

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References

Anantharamaiah, K.R., Radhakrishnan, V.: 1979, *Astron. Astrophys. Letters* **79**, L 9
Burton, W.B., Liszt, H.S.: 1978, *Astrophys. J.* **225**, 815
Cesarsky, D.A., Moffet, A.T., Pasachoff, J.M.: 1973, *Astrophys. J. Letters* **180**, L 1
Clark, G.B.: 1965, *Astrophys. J.* **142**, 1398
Crovisier, J.: 1978, *Astron. Astrophys.* **70**, 43
Kerr, F.J.: 1961, *Monthly Notices Roy. Astron. Soc.* **123**, 327
Oort, J.H.: 1974, in *Galactic Radio Astronomy*, IAU *Symp.* No. 60, Reidel
Radhakrishnan, V., Goss, W.M.: 1972, *Astrophys. J. Suppl.* **24**, 161
Radhakrishnan, V., Goss, W.M., Murray, J.D., Brooks, J.W.: 1972, *Astrophys. J. Suppl.* **24**, 49
Sanders, R.H., Wrixon, G.T.: 1973, *Astron. Astrophys.* **26**, 365
Sanders, R.H., Wrixon, G.T., Mebold, U.: 1977, *Astron. Astrophys.* **61**, 329
Sarma, N.V.G., Mohanty, D.K.: 1978, *Monthly Notices Roy. Astron. Soc.* **184**, 181
Schwarz, U.J., Shaver, P.A., Ekers, R.D.: 1977, *Astron. Astrophys.* **54**, 863
van Woerden, H.: 1967, in *Structure and Motions in the Interstellar Medium*, IAU *Symp.* No. 31, Reidel