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The H I emission and absorption spectra towards the double radio source 1830–211

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ABSTRACT

The flat-spectrum 1-arcsec double radio source 1830 − 211 has anomalous spectral and structural properties that do not admit inclusion in any of the known subdivisions of conventional Galactic and extragalactic radio sources. We have observed the H I emission and absorption spectra due to Galactic neutral hydrogen towards the source. A comparison suggests that 1830 − 211 is extragalactic, consistent with the hypothesis that the source is an example of the gravitational lensing phenomenon. An unusual warm H I component with a spin temperature of about 1000 K has been detected towards the source. This H I fragment is either a peculiar-velocity cloud or else is located beyond the solar circle and about 2 kpc off the Galactic plane.

Key words: interstellar medium: atoms – interstellar medium: clouds – galaxies: active – gravitational lensing – radio continuum: galaxies – radio lines: atomic.

1 INTRODUCTION

The strong radio source 1830 − 211 (PKS 1830 − 210; $S \sim 12$ Jy at 20-cm wavelength) has recently become the subject of intense observational studies and theoretical modelling, following the discovery by Rao & Subrahmanyan (1988) that the source has anomalous spectral and structural properties. The flat radio spectrum and the well-defined 1-arcsec double structure disallow membership of any of the known categories of extragalactic and Galactic radio sources (Rao & Subrahmanyan 1988; Swarup et al. 1989). Also, the detailed high-resolution radio structure appears to be best understood as arising from the gravitational imaging of a background compact flat-spectrum radio source by a foreground galaxy (Subrahmanyan et al. 1990). The recent detection of a ring-like structure connecting the two components (Jauncey et al. 1991) supports the lensing model. Kochanek (1991) has inverted the radio image to derive implications for the lens potential.

Despite the success of the lensing models in accounting for the gross morphological and spectral characteristics, properties such as the seemingly uncorrelated temporal variations in the flux densities of the two components and the spectral differences between the two components (Subrahmanyan et al. 1990) are incompatible with simple lensing models (Turner 1988). A weak third component has been detected between the two main components with possibly a flatter spectrum than the other two (Subrahmanyan et al. 1990). This suggests that 1830 − 211 could be an extreme example of the double-radio-source phenomenon, in which the outer components are synchrotron self-absorbed below 1 GHz and the core is self-absorbed below about 10 GHz; the high turnover frequencies would then be indicative of unusual compactness in the components. Since the ring discovered by Jauncey et al. (1991) has not been shown to have a constant spectral index, it is not clear that the structure is an 'Einstein ring'. Besides, double radio sources with inversion symmetric structures like that of 1830 − 211 are conventionally believed to arise from precession of the radio ejection axis with respect to the surrounding medium (Lonsdale & Morison 1980; Ekers 1981).

On the celestial sphere, 1830 − 211 is located close to the Galactic plane and in the vicinity of the Galactic Centre (at Galactic coordinates $l = 12.^\circ2$, $b = -5.^\circ7$). Since several peculiar radio sources are known to reside in the Galaxy (notably SS433 and the peculiar radio arcs, filaments and Sgr A* that are observed in the region of the Galactic Centre), it is important to determine whether or not 1830 − 211 is Galactic. Searches for an optical or IR counterpart of the radio object have been unsuccessful (Djorgovski et al. 1992). A standard method for determining the distances to Galactic radio sources has been to compare the H I absorption with emission spectra towards the source. The emission spectrum gives the distribution in velocity of all the H I present in the direction of the source. The absorption

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spectrum demarcates the velocity range over which H I is present between the observer and the source. Together with a model for the kinematics of the H I in the Galaxy, the observations yield an estimate of the distance to the source. In this paper, we present H I absorption and emission spectra towards 1830 − 211 and attempt to establish whether this unique object is Galactic or extragalactic.

2 OBSERVATIONS

2.1 H I emission spectrum

The H I emission spectrum towards 1830 − 211 was estimated from observations using the 14.5 arcmin wide (half-power beamwidth; HPBW) beam of the Parkes telescope. Since 1830 − 211 is a strong radio source, a Galactic H I emission spectrum obtained by pointing the telescope beam directly towards the source would be confused by absorption features in the spectrum of the source. Therefore, we assumed that the distribution of Galactic H I is sufficiently uniform for the emission spectrum towards the source to be obtained by averaging the spectra obtained adjacent to the source position. A set of spectra was measured at eight positions offset from 1830 − 211 and located on a square grid centred on the source. The grid cells had a size of 20 × 20 arcmin^2. At each position, spectra were obtained with 512 frequency channels covering a 5-MHz band in each of two orthogonal linear polarizations. The system temperature was ~ 44 K and the total integration time on each of the eight positions was 20 min. The instrument bandpasses were calibrated by frequency switching. The eight spectra thereby obtained, corresponding to the positions around 1830 − 211, were averaged to give an estimate of the H I emission spectrum towards 1830 − 211. Emission is observed over the velocity range − 15 to + 100 km s^{-1} in all of the eight positions. The average emission spectrum is shown in Fig. 1 (as a continuous line) and has been scaled to give the distribution of beam-averaged brightness temperature of the H I emission over velocities with respect to the local standard of rest (LSR). Also displayed in the figure (in broken lines) are the individual emission spectra observed at positions offset to the north, south, east and west of 1830 − 211. The spectral resolution is 2.06 km s^{-1}. The uncertainty in the temperature scale is expected to be about 10 per cent and is dominated by the error in our assumption that the flux density of the calibrator source PKS 1934 − 638 is 16.4 Jy at a wavelength of 21 cm.

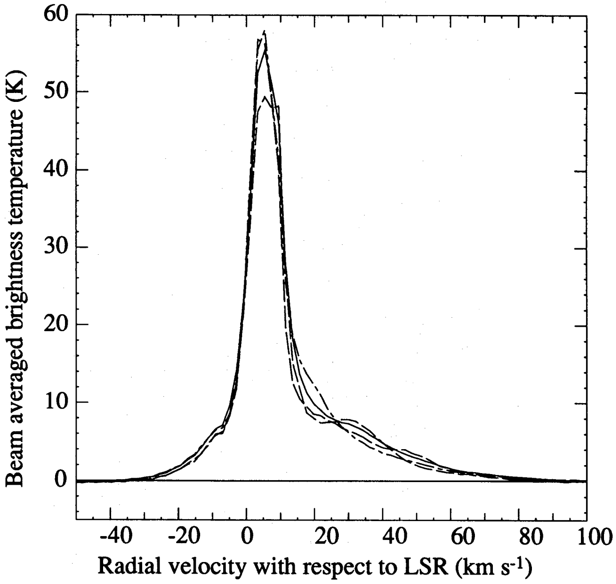

Figure 1. Estimated H I emission spectrum towards 1830 − 211. The average of the spectra observed in the eight positions offset from 1830 − 211 is plotted as a continuous line. Individual spectra observed at offset positions in the north, south, east and west are plotted using broken lines. The emission is plotted as the beam-averaged brightness temperature versus velocity, measured with respect to the local standard of rest.

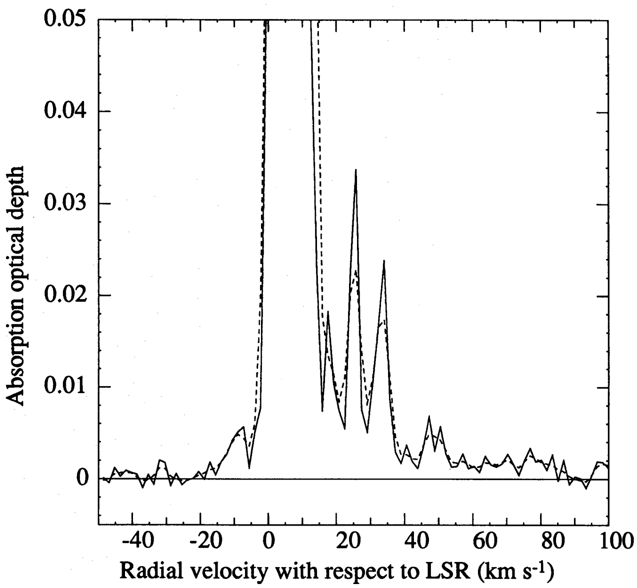

Figure 2. H I absorption spectrum towards 1830 − 211. The absorption is plotted as the optical depth versus velocity, measured with respect to the local standard of rest. The continuous curve shows the raw spectrum while the smoothed spectrum is shown as a dashed line. Parameters of the smoothing window are described in the text.

2.2 H I absorption spectrum

The H I absorption along the line of sight to 1830 − 221 was observed with the Australia Telescope, which is a Fourier synthesis instrument. In its 6-km array configuration, the synthesized beam has an HPBW of ~ 10 arcsec, and 1830 − 211 was unresolved. The source was observed for a total integration time of 8 h, offset 1 arcmin from the phase-tracking centre to avoid possible instrumental errors associated with the phase centre. The amplitudes and phases of the visibilities were calibrated by observations of 1908 − 202 and the instrument bandshapes were calibrated with a 3.5-h observation of PKS 1934 − 638. The spectrum was obtained with a resolution of 1.65 km s^{-1} and over a 4-MHz bandwidth. A linear baseline was fitted by using the channels in the LSR velocity ranges − 150 to − 100 km s^{-1} and + 200 to + 250 km s^{-1}, and subtracted. The absorption spectrum in units of optical depth is shown in Fig. 2 as a continuous line. Peak absorption occurs with an optical depth of 0.9.

3 DISCUSSION

A comparison between the absorption and emission spectra shows that absorption features are present over the whole range of velocities (-15 to $+100$ km s^{-1}) for which we find H I in emission. This suggests that 1830 − 211 is an extragalactic object. At the Galactic longitude of 1830 − 211 ($l = 12^\circ\!.2$), the H I gas within about 17 kpc of the Sun will ideally (assuming a simple axisymmetric velocity field) have positive velocities with respect to the LSR (see, for example, fig. 7.7 of Burton 1988). The H I beyond about 17 kpc is expected to be observed at negative velocities. (The radius of the solar circle is assumed to be 8.5 kpc in this discussion.) Our observations have detected H I with an LSR velocity of -9 km s^{-1}. This component appeared in all of the eight emission spectra for positions around 1830 − 211. In the absorption spectrum, the component appears as a feature with a small optical depth ($\tau = 0.005$) that is located close to $\tau = 0.9$ absorption at $+5$ km s^{-1}. In the simple model for differential Galactic rotation, the component is expected to be located on the far side of the Galaxy and about 19 kpc from the Sun. The detection of this component in both the emission and absorption spectra is simply interpreted as indicating that 1830 − 211 is located beyond the solar circle and is most likely, therefore, an extragalactic object.

Establishment of the reality of the absorption feature at -9 km s^{-1} is crucial to the inference that 1820 − 211 is extragalactic, and we now give reasons for believing this feature to be genuine. The absorption spectrum was separately measured in each of two orthogonal linear polarizations with different instrumental bandshapes and which were independently calibrated. Both of these spectra show the absorption feature. H I observations with the Australia Telescope towards the Magellanic Clouds and Stream (Mebold et al. 1991) have shown that the instrument does not produce spurious features at the level of $\tau = 0.002$. Since the raw autocorrelation spectrum in Fig. 2 (continous line) has not been smoothed, the channel bandpass response functions have high sidelobe levels, with the result that spurious features could be produced in frequency channels close to those having strong absorption. We have confirmed that the -9 km s^{-1} absorption feature is not spurious by verifying that the feature appears in a spectrum that has been smoothed with a Blackman Harris 3-term window (Harris 1978). The spectrum was smoothed by multiplying its Fourier transform by a window function:

$$w(m) = a_0 - a_1 \cos(2\pi m/n) + a_2 \cos(4\pi m/n), \tag{1}$$

where $a_0 = 0.44959$, $a_1 = 0.49364$ and $a_2 = 0.05677$, and $w(m)$ is the weight given to the mth point of the n-point Fourier transform (which has its centre at $m = n/2$). The consequence of windowing the transform is to obtain a smoothed spectrum in which each spectral point represents the response of a filter that has an HPBW of 2.15 channels and whose highest sidelobe is at a level of -31 dB (<0.1 per cent of the peak response). The continuum flux density of 1830 − 211 at 21-cm wavelength is 11.5 Jy and peak absorption occurs at $+5$ km s^{-1} with a dip of 7 Jy. The adopted windowing ensures that the smoothed spectrum would not have spurious sidelobe responses exceeding 6 mJy, corresponding to an optical depth of $\tau = 0.0005$. The observed feature at -9 km s^{-1} has an optical depth that is a factor of 10 larger and, therefore, is not a spurious sidelobe response. The smoothed spectrum is also shown in Fig. 2 as a dashed line.

The line of sight towards 1830 − 211 passes within 2 kpc of the Galactic Centre and is about 2 kpc below the Galactic plane at the solar circle on the far side of the Galaxy. The H I gas components in the Galactic disc have rms peculiar velocities of the order of 10 km s^{-1} (Mihalas & Binney 1981) and hence it is plausible that the -9 km s^{-1} feature which we observe is located within 2 kpc of the Sun. Another possible location is within the innermost few kpc of the Galaxy where large deviations from circular motion have been observed. We will now consider these alternatives.

The distribution of H I in the central region of the Galaxy ($R < 4$ kpc) was traced by Rougoor (1964). At a Galactic longitude of $12^\circ\!.2$, H I was observed with positive velocities with respect to the LSR and was inferred to lie in an expanding arm on the far side of the nucleus. The H I gas within 2 kpc of the Galactic nucleus has been modelled as being distributed in a tilted bar (Liszt & Burton 1980) with components moving in highly elliptical paths. If the H I at -9 km s^{-1} were located in these central regions, the component would necessarily have to be counter-rotating with at least 60 km s^{-1} velocity with respect to the observed structures, and this is highly unlikely. In addition, the H I layer in the inner Galaxy has a full thickness to half-density of about 220 pc, and the H I column density decreases radially inwards from about $R = 5$ kpc towards the Galactic Centre (Burton & Gordon 1978). It is therefore unlikely that H I clouds would be observable at a distance of 1 kpc below the Galactic plane in the central region.

In the Galactic disc, cold H I components are observed to have rms peculiar velocities of about 5–7 km s^{-1}, and the peculiar velocities are often believed to originate in interactions with giant molecular clouds and as a result of accelerations in the local gravitational potentials of spiral arms. Although it is generally accepted that we are not in an arm at present, clouds within a few kpc of the Sun may have some velocity memory of a past encounter. The observed velocity of -9 km s^{-1} towards a small galactic longitude implies, however, that this H I component would have a radial peculiar velocity if it were located in the vicinity of the Sun, whereas the models for generating peculiar velocities in the disc predict these accelerations to be along the arms, so this argues against the -9 km s^{-1} component being nearby. But, since the magnitude of the peculiar velocity is similar to the rms velocity dispersion, we cannot rule out the possibility that the -9 km s^{-1} H I, from considerations of its kinematics, is located within 2 kpc of the Sun. If this H I component were nearby gas, or if the absorption feature in the spectrum at -9 km s^{-1} were not real, then the presence of absorption features at all positive velocities in which we see H I in emission only indicates that 1830 − 211 is located beyond about 8 kpc and we cannot be certain that the source is extragalactic.

We have traced the distribution of the -9 km s^{-1} feature in the Leiden/Green Bank H I survey (Burton & te Lintel Hekkert 1986) and deduce that the H I gas component has an angular extent less than a few degrees. The H I emission spectrum indicates an H I column density of about 1×10^{20} cm^{-2} in the feature. The emission is believed to arise in the warm H I component of the interstellar medium. If we assume that the -9 km s^{-1} H I component has a line-of-sight depth similar to its extent in the plane of the sky, we infer that the gas would have an unusually low density (below ~ 0.5 cm^{-3}) if the component were located beyond ~ 2 kpc from the Sun. Nevertheless, the H I component could be located at a distance greater by an order of magnitude if the line-of-sight depth were a tenth of its extent on the celestial plane.

The peak brightness temperature of 6 K, together with the optical depth of 0.0005, suggests that the cold H I which dominates the -9 km s^{-1} absorption has a spin temperature of, at most, 1250 K. The absorption feature is unusually broad and has a full width at half maximum of 7.5 km s^{-1}, corresponding to a Doppler temperature of 7000 K. These indicate that we are perhaps observing an unusual warm H I component with a low density, although the absorption could be a blend of multiple absorption features due to cold H I clouds with a distribution in velocities. A relatively higher temperature and lower density for the H I are consistent with the hypothesis that the component is located about 2 kpc off the Galactic plane and several kpc from the Sun.

The preceding discussions have assumed that the mean of the emission spectra obtained at positions around 1830 − 211 is appropriate for comparison with the absorption spectrum towards the source. The emission spectra (Fig. 1) show variations on the 20-arcmin scale and there could be variations on smaller scales which would affect the derivation of parameters of the -9 km s^{-1} feature.

To summarize, the observations suggest that the -9 km s^{-1} H I component is located just beyond the solar circle on the far side of the Galaxy and therefore about 2 kpc below the plane of the Galaxy. At the Galactic longitude of 1830 − 211, the warp in the outer Galaxy does not cause any significant departures of the H I gas layer from the Galactic equator. The H I disc of the Galaxy has an rms scaleheight of about 250 pc at the solar circle and, if the -9 km s^{-1} feature originates 3 to 4 kpc outside the solar circle, it could be part of the flaring in the outer Galactic disc.

Several H I fragments have been detected in our Galaxy with peculiar velocities very different from those expected from circular differential Galactic rotation models (Wakker 1990 and references therein). If the -9 km s^{-1} cloud is indeed of this peculiar-velocity class, it represents a unique opportunity for determining the cloud composition through studies of absorption against the strong radio source 1830 − 211. To date, only one such high-velocity cloud has been detected in absorption (Wakker 1990) and the derived spin temperature in that case is 50 K, significantly lower than the value we have obtained.

4 CONCLUSIONS

We have measured the H I emission and absorption spectra due to Galactic neutral hydrogen towards the gravitational lensing candidate 1830 − 211. We observed absorption over the whole range of velocities for which emission was detected. In particular, we have detected an unusually warm H I component at an LSR velocity of -9 km s^{-1} which we locate beyond the solar circle on the far side of the Galaxy. The observations confirm that 1830 − 211 is extragalactic, despite its location close to the Galactic plane and at a low Galactic longitude.

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