Imaging the z=0.9 Absorbing Cloud toward 1830-211

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Abstract. We present spectroscopic imaging observations of the molecular and HI 21cm absorbing cloud at z = 0.885 toward the ‘Einstein ring’ radio source PKS 1830-211. We derive a cloud size between 10 h⁻¹ pc and 600 h⁻¹ pc, and M(H₂) > 2.6×10⁴ h⁻² M☉. The temperature of the ambient radiation field is 4.5±1.5 K, consistent with the microwave background temperature at z = 0.885. The velocity difference for absorption on opposite sides of the ring is -146 km s⁻¹, which is consistent with the galaxian rotation velocity derived from gravitational lens models.

Wiklind and Combes [6] have discovered a strong molecular absorption line system toward the ‘Einstein ring’ radio source 1830-211 at z = 0.885 with N(H₂) = 3×10²² cm⁻² [7] [2]. We have begun an extensive program of imaging the pc- and kpc-scale structures in this absorbing cloud in many molecular species and transitions in order to study the astrochemistry, physical conditions, structures, and dynamics of the dense ISM in this system.

The VLA 47 GHz image and spectra of the redshifted HCN(1-0) absorption toward 1830-211 are shown in Fig. 1. There is strong absorption seen toward the SW radio component at z = 0.88582 with a peak optical depth of 2.5, and no absorption toward the NE component at this redshift to an optical depth limit of 0.012 (3σ). There is a much weaker absorption line seen only toward the NE radio component at z = 0.88491 (= -146 km s⁻¹ relative to the strong line), with a peak optical depth of 0.04. The fact that the absorption along the line of sight to the SW component is different from that toward the NE component implies that this must be absorption by gas in a cosmologically intervening galaxy (presumably the lens), and not at the radio source redshift. Both the NE and SW radio components are spatially extended, and we can set a limit of 0.3 (3σ) to the optical depth toward the ‘tail’ of the SW component, implying an upper limit to the main cloud size of 600 h⁻¹ pc.

The VLBA image at 24 GHz and spectra of redshifted HC₃N(5-4) absorption are shown in Fig. 2. The continuum source shows a possible core-jet extending ≈ 2 mas to the northwest. The spectra show an increase in absorbed flux density going to coarser resolution, suggesting a lower limit to the cloud size of 2.5 mas = 10 h⁻¹ pc, although observations of HC₃N(3-2) absorption indicate that there may be spatial sub-structure with velocity. The upper limit to the volume averaged H₂ density is ∼ 1000 cm⁻³, and the lower limit to the mass is: M(H₂) > 2.6×10⁴ h⁻² M☉. These values are comparable to those found for giant molecular cloud complexes in our own galaxy [3].

From VLA observations of HC₃N (3-2) and (5-4) we derive a temperature
for the ambient radiation field of $4.5^{+1.5}_{-0.6}$ K, consistent with the temperature of the microwave background at $z = 0.885$. Absorption is seen by free radicals ($C_3H_2$), and by molecular ions (HCO$^+$), characteristic of translucent Galactic molecular clouds. The absorption line velocity structure varies significantly between different molecular species (Fig. 3b). We derive a Carbon isotope ratio in the molecular gas phase of: $^{13}C/^{12}C = 35$, which is consistent with significant fractionation, and a mature gas phase chemistry. We do not detect deuterated HCN, leading to the limit: $\frac{HCN}{DCN} > 200$, suggesting a molecular formation temperature $\geq 20$ K.

Neutral hydrogen 21cm absorption has been detected toward 1830-211 (Fig. 3). Absorption is detected at both $z = 0.88582$ with $N$(HI) $\approx 0.5 \times 10^{19}$ $T_s f cm^{-2}$ and at $z = 0.88491$ with $N$(HI) $\approx 1.0 \times 10^{19}$ $T_s f cm^{-2}$, where $T_s$ is the spin temperature and $f$ is the covering factor. While the HI 21cm observations do not spatially resolve the radio continuum source, we can infer from the molecular imaging that the HI absorption at $z = 0.88491$ is toward the NE radio component, while that at $z = 0.88582$ is toward the SW component. Assuming a Galactic dust-to-gas ratio implies rest frame visual extinctions $\geq 1$ toward both radio components, for $T_s > 100$ K. However, the ratio of $H_2$ to HI column densities differs by about two orders of magnitude between the two absorbing systems (assuming similar $T_s$ values), hence one might also expect a variable dust-to-gas ratio.

The velocity difference between the absorption toward the NE and SW components can be used to check the gravitational lens model by assuming Keplerian rotation. From the lens model of Nair et al., we calculate an expected velocity difference between the two lines-of-sight of 144 km s$^{-1}$, under the (very uncertain) assumption that the inclination angle of the lensing galaxy is given by the ellipticity of the lens mass distribution. This is fortuitously close to the observed velocity separation of 146 km s$^{-1}$. High resolution infrared imaging is required to constrain the inclination angle of the lens, and thereby allow for a fundamental check on gravitational lens theory.

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Figure 1: The upper frame shows the continuum image of 1830-211 made with the VLA at 47 GHz with a resolution of 0.1". The contour levels are a geometric progression in square root two, and the first level is 7.5 mJy/beam. The lower figure shows redshifted HCN(1-0) absorption spectra toward the two peaks in the continuum image (designated SW and NE). Zero velocity corresponds to $z_\odot = 0.88582$. The spectra have been converted to optical depth using the continuum surface brightness at each position. The upper spectrum is at the peak surface brightness of the SW radio component, where $F_\nu = 0.91$ Jy/beam. The dash line is a Gaussian fit to the data, with a peak optical depth of 2.5, and FWHM = 25$\pm$5 km s$^{-1}$ centered at 0 km s$^{-1}$. The lower spectrum is toward the NE radio component, where $F_\nu = 1.1$ Jy/beam, and the Gaussian Fit parameters are: peak optical depth of 0.043 and FWHM = 16$\pm$5 km s$^{-1}$ centered at -146$\pm$1 km s$^{-1}$.
Figure 2: The figure on the right shows the continuum image of the SW component of 1830-211 at 24 GHz made with the VLBA at 1 mas resolution. Contouring is the same as Fig. 1, with the first level = 3 mJy/beam. The figure on the left shows VLBA spectra of redshifted HC$_3$N(5-4) absorption toward the SW component. Zero velocity corresponds to $z_\odot = 0.88582$. The dash line is a spectrum at the peak surface brightness at 1mas resolution. The solid line is the same spectrum, but now at 2.5mas resolution. The peak line flux density increases from $26\pm 4$ mJy at 1 mas resolution to $42\pm 8$ mJy at 2.5 mas resolution, suggesting a lower limit to the cloud size of 2.5mas.

Figure 3: The figure on the right shows a reanalysis of the HI 21cm absorption spectrum toward 1830-211 made with the 140’ telescope [3], corrected to optical depth using the continuum flux density of 10 Jy. Zero velocity corresponds to $z_\odot = 0.88582$. Note that the channels around zero velocity were corrupted by terrestrial interference, so only the absorption component near -146 km s$^{-1}$ was detected. The Gaussian fit parameters for this HI component are: peak opacity = $0.041\pm 0.004$, and FWHM = $127\pm 6$ km s$^{-1}$ centered at $-141\pm 2$ km s$^{-1}$. The WSRT spectrum of Chengalur and de Bruyn [1] shows HI 21cm absorption at zero velocity with about half the peak optical depth as that seen at $-141$ km s$^{-1}$. The figure on the left shows redshifted absorption spectra of C$_3$H$_2$ (2$_{12}$-2$_{01}$) (solid line) and HC$_3$N (3-2) (dashed line) for the main molecular absorption line system at $z_\odot = 0.88582$. The spectra have been normalized to unit line strength simply to demonstrate the different velocity structures in the different species.