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DETECTION OF AN H I DISK IN HYDRA A?

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ABSTRACT

We present new observations of the H I absorption system seen toward the core of the radio galaxy Hydra A, which is the central galaxy in a cooling flow cluster Abell 780. Our improved spatial ($\sim 2''$) and velocity (~ 1.4 km s^{-1}) resolutions indicate that the absorption arises very close to the nucleus, probably in a gas disk located in the central regions of the galaxy. There is no indication that any of the absorption arises in the cooling flow.

The H I absorption is seen only toward the core and is within ~ 100 km s^{-1} of the systemic velocity. The absorption covers a velocity range ~ 100 km s^{-1}. It can be decomposed into six Gaussian components with widths ~ 10–20 km s^{-1} and optical depths ~ 0.1–0.5. No narrow line features (~ 1 km s^{-1}) were detected in Hydra A to a 3 σ optical depth limit of 0.06.

Subject headings: cooling flows — galaxies: individual (Hydra A) — radio lines: galaxies

1. INTRODUCTION

Hydra A is the dominant member of a poor Abell cluster of galaxies, A780. It has been well studied in radio, optical, and X-rays (Simkin 1979; Ekers & Simkin 1983; Baum et al. 1988; Taylor et al. 1990; David et al. 1990). The X-ray image of this cluster from *Einstein* indicates the presence of a cooling flow with the maximum intensity in X-rays coincident with the source Hydra A. The estimated mass deposition rate is ~ 600 $M_\odot$ yr^{-1} (David et al. 1990). The optical observations in [O III], Hβ, Hα and in stellar absorption lines indicate the presence of a rotating disk of gas and stars around the nucleus of Hydra A and has been traced to ~ 10 kpc from the nucleus (Ekers & Simkin 1983; Baum et al. 1988). The radio observations of Hydra A reveal a core and two well-collimated curved jets and two diffuse radio lobes. The morphology is similar to that of wide-angle tail radio sources (Taylor et al. 1990). The optical disk is oriented roughly perpendicular to the radio jets.

Here we present new observations of an H I absorption system found by us as a by-product of a search for H I gas in cooling flow clusters. This line was first reported by G. Taylor (private communication). In this earlier study we observed three cooling flow clusters Virgo (Virgo A), Abell 2199 (3C 338), and Abell 780 (Hydra A) with the Very Large Array (VLA)[4] to detect spatially distributed and wide absorption lines due to cold H I gas that might be present in them (Dwarakanath, van Gorkom, & Owen 1994). Our velocity coverage was ~ 2600 km s^{-1}, and the velocity resolution was ~ 87 km s^{-1}. We did not detect any such absorption to an optical depth limit (3 σ) of 0.0005 over a typical velocity range of 500 km s^{-1}. However, we detected an absorption line toward the core of Hydra A. This line was unresolved, and the nature of the absorbing gas was unclear. The line could be a blend of a few narrow lines (widths ~ 1 km s^{-1}), indicating the presence of cold clouds near the core. The line could also be a single wide line (~ 50 km s^{-1}) and indicative of an H I disk around the nucleus, as has been seen in many isolated radio galaxies (van Gorkom et al. 1989). We have observed Hydra A with improved spectral and spatial resolution to investigate the nature of this system.

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2. OBSERVATIONS AND RESULTS

The observations were carried out during 1994 March when the VLA was in its A configuration. A description of the VLA is given by Napier, Thompson, & Ekers (1983). We used a bandwidth of 1.56 MHz, 256 channels, and on-line Hanning smoothing resulting in a frequency resolution of 6.1 kHz. The band was centered at 16,291 km s^{-1}. The velocity resolution was 1.43 km s^{-1} with a usable velocity coverage ~ 300 km s^{-1}. The synthesized beam was $2''.7 \times 1''.5$ at a position angle of $-9^\circ.2$. A suitable bandpass calibrator was observed often and was used to correct for the instrumental amplitudes and phases. The line-free channels from the flat portion of the spectrum were used to construct a continuum database for Hydra A. A continuum image of Hydra A obtained from this data is shown in Figure 1. The continuum was subtracted from the spectral line data by performing a linear fit to the visibilities over the channels which were line-free and which were not affected by the edge effects of the filter. Spectral cubes were made using natural weighting, and the rms in each channel was ~ 3 mJy beam^{-1}, close to the expected value. The cubes were examined by eye for any spectral features.

The spectra toward the core and the local maxima in the northern and southern lobes of Hydra A after an off-line Hanning smoothing over two channels are shown in Figure 2. The H I absorption features toward the core are evident. In Figure 3 the corresponding optical depth profile toward the core is shown along with a six Gaussian component best fit (least χ^2). The velocities, full widths at half-maxima, and the corresponding optical depths of the six components are given in Table 1. Also given in Table 1 are the column densities of H I assuming a spin temperature of 100 K. No spectral features were detected anywhere else in the spectral cube to the detection limit (3 σ) of 9 mJy beam^{-1}. In the direction of the maxima in the northern and southern lobes of Hydra A this corresponds to a 3 σ optical depth limit $\sim 5 \times 10^{-3}$ and $\sim 7 \times 10^{-3}$, respectively.

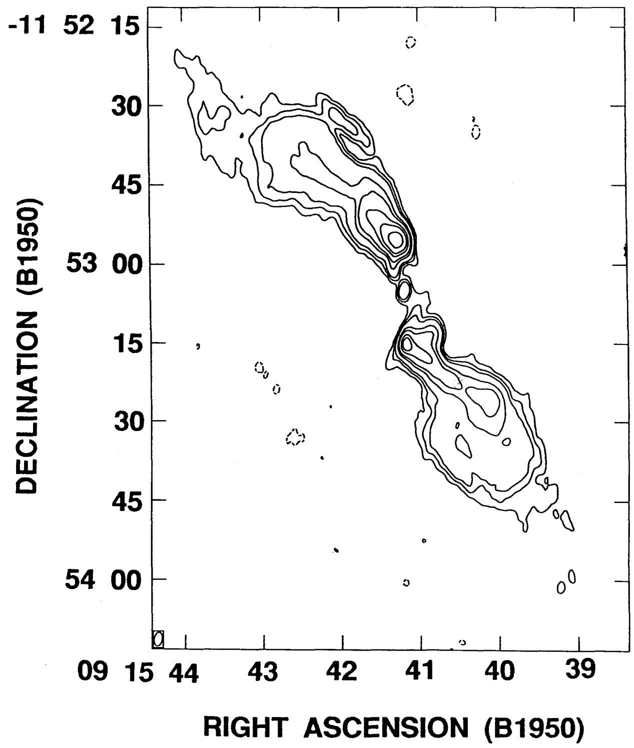

FIG. 1.—A continuum image of Hydra A at a frequency of 1347 MHz. The synthesized beam is 2″.7 × 1″.5 at a position angle of −9°.19. The contours are at −15, 15, 33, 60, 180, 300, 600, 900, and 1500 mJy beam^{-1}.

3. DISCUSSION

The H I absorption in Hydra A which we have detected has important implications for both the cooling flow models and the nature of the H I gas found in the centers of radio galaxies.

The ultimate fate of the cool gas condensing out of the hot intracluster gas is unclear. It has been proposed that this gas might end up in the form of small ($\ll 1$ pc), cold (~ 10 K), optically thick ($\tau > 1$) H I clouds with a covering factor ~ 1 within a cooling radius ~ 100 kpc (Loewenstein & Fabian 1990; White et al. 1991; Daines, Fabian, & Thomas 1994). Such clouds should appear in absorption in the 21 cm line of atomic hydrogen against the strong background radio source Hydra A. It was apparent from our earlier observations of Hydra A that such large amounts ($\sim 10^{11}$ $M_{\odot}$) of cold clouds could not be present in Hydra A unless their covering factor was much less than 1 and/or the spin temperature of H I was less than 10 K (Dwarakanath et al. 1994). Interpretation of the

TABLE 1

ESTIMATED PARAMETERS OF THE H I CLOUDS

Component Number	Velocity (km s^{-1})	ΔV (km s^{-1})	τ	$N_{\rm H\,I}$ (10^{20} cm^{-2})
1	16324	11	0.12	2.4
2	16309	9.5	0.09	1.6
3	16292	13	0.33	7.8
4	16279	11	0.42	8.4
5	16262	20.8	0.52	19.7
6	16229	28.5	0.04	2.1

NOTES.—Velocities are heliocentric and optical definition with no relativistic correction. ΔV is full width at half-maximum. $N_{\rm H\,I}$ is estimated assuming the spin temperature of H I to be 100 K.

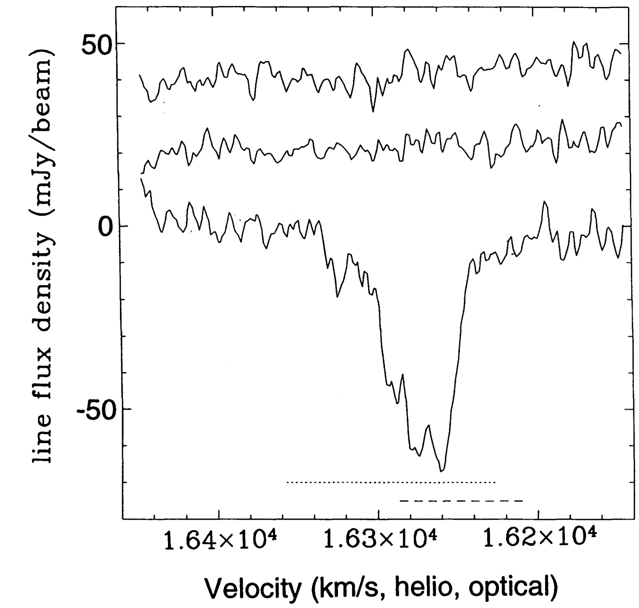

FIG. 2.—Spectrum toward the core of Hydra A at α (1950) 09^{h}15^{m}41^{s}.191 and δ (1950) −11°53′5″.20 showing several components of absorption. Best-fit continuum has been subtracted before producing this spectrum. The core flux is 164.7 mJy beam^{-1} and is unresolved. The velocity definition is heliocentric and optical without relativistic correction. The dashed line indicates the extent of uncertainty in the velocity of the emission-line system as estimated from [O II] 3727 line. The dotted line indicates the corresponding uncertainty as estimated from the stellar absorption lines. Both these measurements are from Owen (1994). The two other spectra are toward the two local maxima in Fig. 1. The southern peak is 1.3 Jy beam^{-1}, and its spectrum is offset from 0 by 20 mJy beam^{-1}. The northern peak is 1.9 Jy beam^{-1}, and its spectrum is offset from 0 by 40 mJy beam^{-1}. The corresponding limits on optical depths are (3 σ) 7×10^{-3} and 5×10^{-3}.

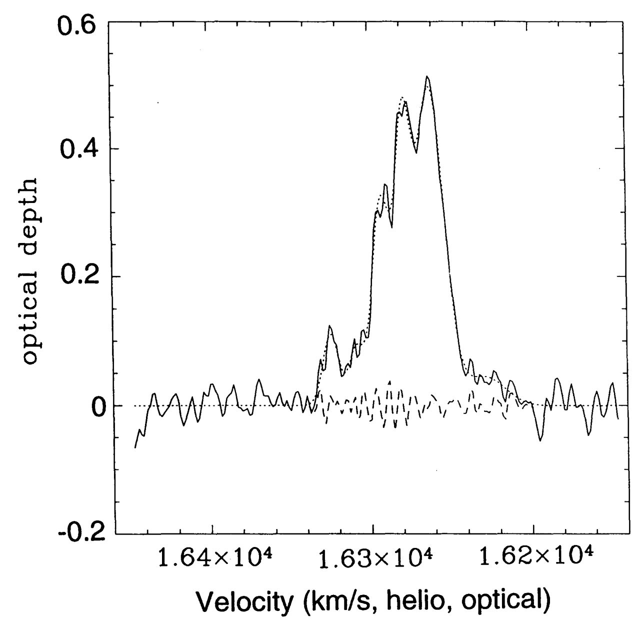

FIG. 3.—Optical depth profile toward the core. The dotted line is the best fit with 6 Gaussian components. The dashed line is the residual over the range of velocities covered by the Gaussians.

H I absorption detected toward the core of Hydra A in those observations was hampered by the poor spectral resolution (~ 87 km s^{-1}). The present observations with their improved spectral resolution (~ 1 km s^{-1}) have alleviated that difficulty. The core in Hydra A is unresolved at all VLA resolutions (Taylor et al. 1990). Based on its flux density measurements at nearby frequencies, the turnover frequency can be estimated to be ~ 3 GHz with a peak flux density ~ 0.5 Jy. This implies a core size $\sim 0.2 T_{12}^{-0.5}$ pc at the distance to Hydra A ($H_0 = 75$ km s^{-1} Mpc^{-1}), where T_{12} is the brightness temperature of the core in units of 10^{12} K. Hence, the spatial resolution for H I absorption toward the core of Hydra A is set by its size rather than by the synthesized beam size, which is ~ 2 kpc in the present observations. The size of the clouds (d) in pressure equilibrium with the hot intracluster gas can be estimated from $d = 0.003 N_{21} T_{10} P_6^{-1}$ pc, where N_{21} is the column density of H I in units of 10^{21} cm^{-2}, T_{10} is the kinetic temperature ($\sim$spin temperature) of the H I clouds in units of 10 K, and P_6 is the pressure of the intracluster gas in units of 10^6 cm^{-3} K. For expected values of $N_{21} \sim 1$, $T_{10} \sim 1$, and $P_6 \sim 1$ the covering factor of a single cloud is $\sim 10^{-4}$ toward a core of 0.2 pc. Such a single cloud cannot be detected in the present observations. If the covering factor of a system of these clouds is ~ 1, then an ensemble of them will be observed toward the core of Hydra A. If one were to invoke such clouds to account for the observed H I absorption in Hydra A, a very unlikely arrangement of them in velocity will be required. Several thousands of these clous will have to bunch within ~ 10 km s^{-1} to account for one component of the H I absorption profile seen in Figure 2. It is highly unlikely that the observed H I absorption is produced by clouds such as postulated in cooling flow scenarios.

The observed H I absorption toward the core of Hydra A is at a velocity which is consistent within the errors with the systemic velocity. The striking feature of the H I absorption spectrum is the existence of distinct velocity components and the optically thin profiles (Figs. 2 and 3). In addition, no H I absorption was detected to a 3 σ optical depth limit of 0.06 one beam away from the core along the radio jets. This implies that the "vertical" extent of the H I gas is less than ± 2 kpc. Its extent along the perpendicular directions cannot be estimated from the present observations. However, optical observations seem to indicate the existence of a disk-like structure for the line-emitting gas with rotational velocities ~ 200 km s^{-1}. This disk of gas has a rotation axis at a position angle $\sim 30°$, roughly in line with the radio jets (Simkin 1979; Baum et al. 1988). The emission-line gas has been seen up to ~ 10 kpc along the perpendicular direction. The H I gas responsible for the absorption is likely to be in this disk. The presence of an H I disk is also consistent with the blue colors observed within 10 kpc of the core of Hydra A, requiring the presence of cold gas responsible for star formation (McNamara 1995). While the above arguments make an H I disk plausible, they are by no means compelling. The velocity structure of the H I profile can be understood in different scenarios. If the H I gas is indeed in a disk, then it is possible to account for the different velocity components in the absorption profile by H I gas on noncircular orbits at different distances from the core (Gunn 1979; van Gorkom et al. 1989). One difficulty with this picture is the survival of H I clouds in the harsh environment of the cluster gas, particularly when they are not comoving with it (Loewenstein & Fabian 1990). If the H I clouds are comoving with the hot intracluster gas (and hence no frictional drag), then the different velocity components in the H I absorption can arise owing to the turbulence in the hot gas. Several processes contribute toward the turbulence in the intracluster gas, and turbulent velocities in excess of 100 km s^{-1} have been invoked to account for the observed emission-line widths from the centers of cooling flow clusters (Loewenstein & Fabian 1990; Baum 1992). One can also invoke non-coplanar and peculiar motions of the H I gas to explain the observed absorption spectrum. Such models have been successful in explaining the H I absorption spectrum toward the Galactic center (Liszt, Burton, & van der Hulst 1985). In the case of Hydra A the kinematics of the line-emitting gas and stellar disk seem complex. At some positions along the line-emitting gas disk there are differences as large as 500 km s^{-1} between the velocities estimated from the emission lines and the stellar absorption lines. This might be indicative of peculiar motions which can also be shared by the H I gas.

There are four other cooling flow clusters, 2A 0335+096, MKW 3s, A2597, and Perseus A, and some isolated radio galaxies in which H I absorptions have been detected (McNamara, Bregman, & O'Connell 1990; O'Dea, Baum, & Gallimore 1994; Jaffe 1992; van Gorkom et al. 1989; van der Hulst, Golisch, & Haschick 1983). There are no characteristics in the H I absorption lines detected in cooling flow clusters that distinguish them from the ones observed toward isolated radio galaxies. Hydra A and Cen A, although the former is in a cooling flow cluster and the latter is an isolated radio galaxy, are quite similar in having large optical depths (>0.5) and narrow line widths (~ 10 km s^{-1}). Most other systems have smaller optical depths (<0.1) and wider (~ 35–100 km s^{-1}) H I absorption lines. Perseus A, on the other hand, shows two H I absorption lines toward its core with widths ~ 477 and 66 km s^{-1} and optical depths ~ 0.0021 and 0.00087. This is in contrast to that observed in Hydra A, although both are known to be cooling flow clusters. Clearly, there is no obvious signature of cooling flow in the H I observations.

4. SUMMARY

We detect H I absorption toward the core of Hydra A. The detected H I absorption is within ~ 100 km s^{-1} of the systemic velocity of Hydra A. The absorption is consistent with six Gaussian components spread over ~ 100 km s^{-1} with full widths at half-maxima ~ 10 km s^{-1}. Their optical depths range from 0.1–0.5. This absorption is unlikely to be caused by a system of cold clouds with properties as postulated in cooling flow scenarios. The H I gas causing the absorption is likely to be in the form of a disk around the core. Optical observations seem to indicate a similar picture for the line-emitting gas. We do not detect any narrow (~ 1 km s^{-1}) H I absorption features in Hydra A to a 3 σ optical depth limit of 0.06.

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