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NEUTRAL-HYDROGEN ABSORPTION IN THE RADIO GALAXY 3C 293

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ABSTRACT

Neutral hydrogen has been detected in absorption in the radio galaxy 3C 293 at 21 cm wavelength. A central absorption feature lies at a velocity of 13,500 km s^{-1}, which agrees with the optical emission-line redshift for the galaxy of 13,491 km s^{-1}. An additional feature may be seen at 13,382 km s^{-1} with an optical depth of 0.030 as compared with an optical depth of 0.085 for the central feature. A possible feature may exist as a shallow trough redward of the central feature with an average optical depth of 0.05. The total velocity width at the base of the line, including the possible shallow feature, is 480 km s^{-1}. The total column density for the whole feature is $N_H = 1.8 \times 10^{19}\, T_s$H I atoms cm^{-2}. The velocity structure of the observed feature resembles that of the lines in Cen A, NGC 253, and NGC 4945.

Subject headings: galaxies: general — radio sources: galaxies — radio sources: 21 cm radiation

I. INTRODUCTION

As a Cambridge source, 3C 293 has enjoyed much attention in the past. The source has been identified with a D5–6 galaxy (Burbidge and Crowne 1979). The galaxy contains a bright nucleus and an extensive, slightly asymmetric, outer envelope, which led some authors to suggest that the object is an S0 (Colla *et al.* 1975) or an Sb galaxy (Sandage 1966). Wyndham (1966) suggests the existence of an absorbing dust lane in the object, which is oriented roughly toward the NE.

The visual magnitude of the object is approximately 14.3 (Burbidge 1967; Burbidge and Crowne 1979). A One Mile Telescope radio map of 3C 293 at 21 cm wavelength (Mackay 1969) encompasses three optical objects. Besides the central object, there is a faint 19.5 mag red galaxy at 1′ to the NW and a neutral-color object close to the PSS plate limits at 1′.5 to the NW. Wills and Parker (1966) suggest that besides the central object there is another, smaller, spherical object of 16.5 mag to the SW, connected to the former by a blue nebulous filament.

The redshift has been determined on the basis of the two detected lines, [O II] λ3727 and Hα (Sandage 1966; Burbidge 1967). The redshift of the object is $z = 0.045$ for the Hα line and 0.0454 for the O II line.

The radio spectrum of 3C 293 is well documented. Högbom and Carlsson (1974) find that the nuclear source has a flux of 3.76 Jy at 1415 MHz, and Jenkins, Pooley, and Riley (1977) find a nuclear source of 1.7 Jy at 5 GHz. These results are consistent with a decomposition of the total spectrum into an extended component and a self-absorbed compact component.

The radio structure of the galaxy is characterized by a compact source of 2″ E–W and <2″ N–S (Colla *et al.* 1975; Jenkins, Pooley, and Riley 1977). The optical nucleus lies 1″.7 N of the radio position. There is an extension toward the NW in the 5 GHz Cambridge 5 km map. This extension also exists in an earlier Westerbork map at 1415 MHz (Högbom and Carlsson 1974) and a Cambridge One Mile map at 1407 MHz (Mackay 1969). The extension is aligned with the two optical objects toward the NW, and the second peak visible in the Westerbork map roughly coincides with the 19.5 mag object mentioned above. Recent maps of 3C 293 obtained with the VLA confirm the general structure of the source but indicate that the core source is a double source (E. B. Fomalont, private communication).

The nuclear component is 2.2% polarized with a position angle of 64° for the electric vector (Högbom and Carlsson 1974). This orientation is roughly perpendicular to the direction of the NW extension.

In this *Letter* we report on the detection of a broad (480 km s^{-1}), neutral-hydrogen absorption feature at the optical redshift of the 14.3 mag galaxy associated with the radio source 3C 293.

II. OBSERVATIONS

The observations were conducted using the 1000 foot (305 m) telescope of the NAIC[1] at Arecibo, Puerto Rico, during 1979 December. The telescope was equipped with the 6/25 dual-channel parametric cooled up-converter amplifier having a system temperature of approximately 60 K. Two separate autocorrelation spectrometers of 504 channels each were employed. The observations were conducted in the total-power mode, using receiver bandwidths of 5 and 10 MHz. The sensitivity of the telescope was ~5.2 K Jy^{-1} with the 40′ dual circular feed tuned to 1350 MHz.

[1] The National Astronomy and Ionospheric Center is operated by Cornell University under contract with the National Science Foundation.

The radio spectrum of 3C 293 at 21 cm is shown in Figures 1 and 2. The 10 and 5 MHz overall bandwidths employed provide an effective velocity resolution of 4.5 and 2.25 km s^{-1}, respectively. The velocities ($c\Delta\lambda/\lambda_0$) quoted are with respect to the Sun. The spectrum displays a prominent central absorption feature at a velocity of 13,500 $\pm$ 2.25 km s^{-1} having a FWHM of 41 km s^{-1}. This velocity coincides with the Hα line redshift of 3C 293 of 13,491 km s^{-1}. A broad absorption trough on the low-velocity wing of the central feature is evident in the spectrum. This plateau has a FWHM of 135 km s^{-1} and is possibly composed of two blended features. On the high-velocity wing of the central feature there may be an additional feature, which is shallow and extends to a velocity of 13,750 km s^{-1}. This shallow feature is visible in both spectra. Second-order baselines have been fitted to the spectral channels lying outside the absorption features. Although baseline subtractions could produce shallow features like the one observed, we do feel this feature to be real. The small peak in the 10 MHz spectrum at a velocity of 13,600 km s^{-1} does not exist in the 5 MHz spectrum. Although its presence is not inconsistent with the 5 MHz data, it needs further verification.

The main components of the absorption feature were confirmed in 1980 April using the 300 foot (91.4 m)

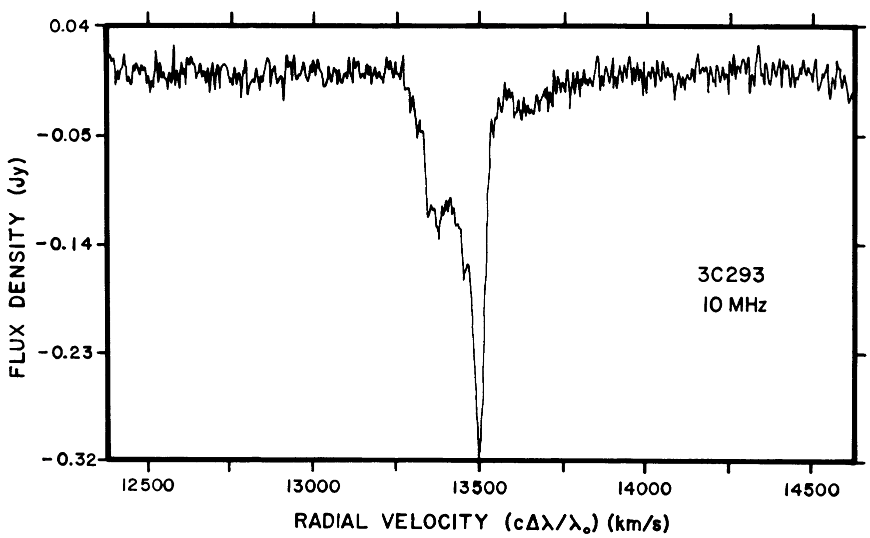

FIG. 1.—Flux density as a function of heliocentric radial velocity for the galaxy 3C 293. The bandwidth is 10 MHz, with an effective velocity resolution of 4.5 km s^{-1}. The integration time is 24 minutes.

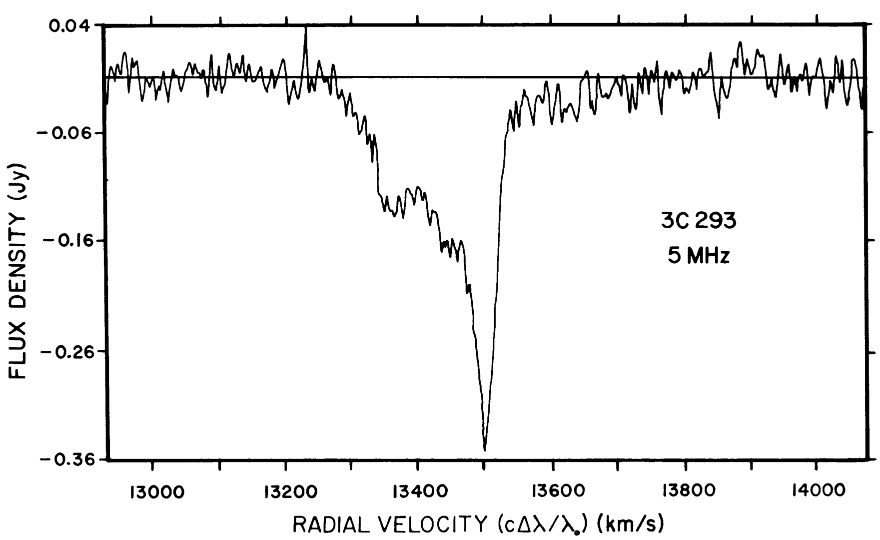

FIG. 2.—Flux density as a function of heliocentric radial velocity $(c\Delta\lambda/\lambda_0)^{-1}$ for the galaxy 3C 293. The bandwidth is 5 MHz, with an effective velocity resolution of 2.25 km s^{-1}. The integration time is 12 minutes.

transit telescope of NRAO[2] in Green Bank, West Virginia.

Adopting a nuclear source flux density of 3.76 Jy at 21 cm and assuming that the absorbing material completely covers the radio source, we derive an optical depth for the different features. The results are given in Table 1. The column density for the entire absorption feature, as well as for the individual components, has also been given in the table.

At a distance of 3C 293 of 270 Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}), the 2″ upper limit of the size of the continuum source implies a source diameter of 2.6 kpc. Taking this as an upper limit to the size of the absorbing H I cloud and assuming $T_s = 100$ K, we may derive a lower limit to the H I density for a uniform cloud covering the continuum source of 0.2 atoms cm^{-3}. The associated H I mass of such a cloud would be $5 \times 10^7 M_\odot$.

TABLE 1

ABSORPTION FEATURES IN 3C 293

Feature	Central Velocity (km s^{-1})	Velocity Width (km s^{-1})	Optical Depth	Column Density N_H/T_s (H I atoms cm^{-2} K^{-1})
Central.....	13,500	41(FWHM)	0.085	9.3×10^{18}
Blueward....	13,382	135(FWHM)	0.030	7.4×10^{18}
Redward....	13,650	(200[a])	(0.005[b])	(1.1×10^{18})
Total.......	13,522	480[a]	0.020[b]	1.8×10^{19}

[a] Velocity at base of profile.

[b] Average optical depth.

III. DISCUSSION

The neutral-hydrogen absorption feature in 3C 293 is potentially the broadest absorption line yet detected. The total velocity width at the base of the line is 480 km s^{-1}. In structure, the feature resembles the absorption profiles found in Cen A (NGC 5128; Roberts 1970) and in NGC 253 and NGC 4945 (Whiteoak and Gardner 1973). In these sources, several different lines blend together into one broad feature with a total velocity width of 90–230 km s^{-1}. Absorption lines in the irregular systems M82 (Guélin and Weliachew 1970) and B2 1506+34 (Baan, Haschick, and Greenfield 1978) have a broad "single" line structure with a velocity width of approximately 100 km s^{-1} (FWHM). All these lines stand in sharp contrast with the narrow ($\sim$10 km s^{-1}) lines which have been detected in certain radio galaxies (e.g., NGC 1275: De Young, Roberts, and Saslaw 1973; and Mrk 6: Haschick, Baan, and Burke 1976).

The central feature will be considered to be at the systematic velocity of the galaxy. The radial velocity is then in good agreement with the Hα line velocity of 13,491 km s^{-1} ($z = 0.045$; Sandage 1966). The O II line redshift determination suggests a velocity of 13,611 km s^{-1}. Since the optical nucleus falls within the contours of the 2.6 kpc ($H_0 = 50$ km s^{-1} Mpc^{-1}) radio source, we further assume the radio source to be located at the galactic center.

The origin of the velocity range of the absorption features can be interpreted as being due to rotational and or radial motions. For the simplest case of a symmetric configuration of the radio source and the absorbing neutral-hydrogen cloud, the contribution of rotating gas to the absorption profile will be symmetric as well. Therefore rotation could not account for an asymmetric profile. It can, however, explain the shallow high-velocity feature if it is real, and furthermore we cannot exclude the possibility of a rotational contribution to the central feature itself. The maximum rotation velocity suggested by the absorption profile is approximately 240 km s^{-1}; this value is rather consistent with the possible classification for the galaxy of Sb (see Bosma 1978). Naturally the asymmetry of the absorption features could be accounted for by an asymmetric configuration of the radio source and the absorbing hydrogen.

Optically, outward motions have been observed in NGC 253 (DeMoulin and Burbidge 1970), and there is evidence of noncircular motion in NGC 4945 from the [N II] λ6583 profile. In our own Galaxy, large velocity widths have been observed, and there is evidence that the H I absorption in M82 is due to outflowing gas (Guélin and Weliachew 1970). In this context the features of the absorption line in 3C 293 suggest both inward and outward motion. The outflow feature contains approximately 40% of the absorbing material, and it is most plausible that this material is associated with the disk, possibly in the form of a structure similar to the "3 kpc arm" in our Galaxy. The possible high-velocity feature, which is shallow but of uniform depth, could indicate a continuous inflow in the form of an accretion flow near the nucleus or general inflow in a halo. All absorbing material in purely circular motion could then be represented by the central feature. Although a rotational contribution to the observed velocity range is plausible, it seems that an interpretation involving radial motions is more consistent with observations in other similar galaxies.

A characteristic property of 3C 293, Cen A, NGC 253, and NGC 4945 is that they are all edge-on galaxies. Moreover, 3C 293, Cen A, and NGC 253 each have an absorbing dust lane. A comparison of the absorption features in these galaxies reveals that Cen A and NGC 4945 have a central feature with mainly additional inflow features, while NGC 253 shows a central feature and an outflow feature. The major difference, however, between 3C 293 and the other three galaxies is the magnitude of the in- and outflow velocities. The maximum outflow velocity is 230 km s^{-1}, and if the shallow feature is taken into account the maximum inflow

[2] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

velocity could be as large as 250 km s^{-1} in the case of 3C 293, compared to $<130 \text{ km s}^{-1}$ for NGC 253, NGC 4945, and Cen A.

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