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NEUTRAL HYDROGEN IN THE NORMAL ELLIPTICAL GALAXY NGC 4278

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ABSTRACT

We report the first convincing detection of neutral hydrogen in a structurally normal elliptical galaxy, NGC 4278 (type E1). The observed 21 cm emission-line profile is roughly Gaussian in shape, has a central velocity close to the optical velocity of the galaxy, and has a full width at half-maximum (FWHM) of 470 km s^{-1}. If $D = 16$ Mpc, the H I mass is $7 \times 10^8\ M_\odot$ and the H I mass-to-photographic-luminosity ratio is 0.05 in solar units, a remarkably high value for an elliptical galaxy. The H I is unresolved with a FWHM 10′ beam.

NGC 4278 is a morphologically normal elliptical galaxy but has an unusually intense compact nuclear radio source as well as a relatively bright nuclear emission-line spectrum. It is not known whether the nuclear activity in NGC 4278 is related in some way to the unusually high H I content. Possible sources for the H I include mass loss from stars or infall from the intergalactic medium. Infall models seem more in accord with the data now available. The present situation is perhaps unstable, and possible evolutionary scenarios are briefly mentioned.

Subject headings: galaxies: individual — galaxies: structure — interstellar: matter — radio sources: 21 cm radiation

I. INTRODUCTION

Elliptical galaxies are the archetypal examples of gas-free, pure Population II extragalactic systems. The low incidence of optical line emission, the dominance of old low-mass stars, and the smooth optical structure have long been interpreted as resulting from the absence of interstellar matter (e.g., Baade 1963; Morgan and Mayall 1957; Morgan and Osterbrock 1969; van den Bergh 1972*a*). However, with the growing awareness of the importance of mass loss in the later stages of stellar evolution, it has recently been realized that the existence of galaxies totally devoid of gas would be paradoxical (Tinsley 1972; Gallagher 1972). Several 21 cm, H I surveys have since been undertaken to search for neutral interstellar matter in early-type galaxies; approximately 50 normal ellipticals have been observed to date, but no neutral hydrogen has been detected (Gallagher 1972; Bottinelli, Gouguenheim, and Heidmann 1973; Knapp and Kerr 1974; Shostak, Roberts, and Peterson 1975; Huchtmeier, Tammann, and Wendker 1975; Gallagher, Faber, and Balick 1975, hereafter GFB; Knapp, Kerr, and Williams 1977). Upper limits of 1–5 $\times 10^8\ M_\odot$ have typically been established based on assumed rectangular line profiles with velocity widths of $\sim$300 km s^{-1}.

These limits conflict with even rather conservative estimates for the amount of matter shed from dying stars (Faber and Gallagher 1976). Faber and Gallagher concluded that alternative storage mechanisms are improbable and hypothesized that gas is removed from E galaxies, perhaps by galactic winds, as originally proposed by Mathews and Baker (1971). This is a central problem in understanding the evolutionary history of E galaxies; for if winds are operating, then it is probable that E galaxies have been gas-free since a very early epoch (Larson 1974). Alternatively, if gas is present, more complex evolutionary scenarios are possible. For example, ellipticals could undergo sporadic episodes of star formation (van den Bergh 1972*b*). Computation of evolutionary corrections required for the use of ellipticals as cosmological distance standards would then be more challenging.

An interesting exception to the routinely negative results from H I observations of ellipticals has been the E1 galaxy NGC 4278. Both Gallagher (1972) and Huchtmeier, Tammann, and Wendker (1975) reported marginal detections, with some important inconsistencies. Observations by GFB agreed with those by Gallagher (1972) but were also inconclusive. We have therefore carefully reobserved this galaxy using two different telescopes and report the detection of 21 cm, H I line emission.

II. OBSERVATIONS

A first series of observations was made in 1976 March with the 43 m equatorial telescope of the National Radio Astronomy Observatory.[1] The dual-polarization receiver having a system temperature of ~50 K was used with the 384-channel autocorrelation receiver operated in the parallel mode. Data were acquired and reduced following the procedure described by GFB.

The results of these observations are shown in Figure 1. The reality of the line feature was tested by shifting the heliocentric velocity of the bandpass from $v = 630$ km s^{-1} to $v = 925$ km s^{-1} on one night. The data shown here are all from the observations centered at 630 km s^{-1}. The data from the velocity-shifted observations suggest that it is possible that the shape of the line has been affected by a spurious instrumental feature near 700 km s^{-1}.

Although these observations indicate the existence of H I in NGC 4278, the signal-to-noise ratio is poor. A second set of observations was therefore made in 1976 May with the NRAO 91 m transit telescope; the cooled, dual-polarization 21 cm parametric amplifier front end; and the 384-channel autocorrelation spectral-line receiver. The correlator was used in parallel mode with a bandwidth of 10 MHz (11 km s^{-1} per channel); the two orthogonally polarized front-end receivers were detected independently. The instantaneous (2 dB) bandwidth of each front-end receiver was ~25 MHz (centered on 1415 MHz), which produced very stable baselines; the system temperature was ~50 K. The observations were made in the total-power observing mode by first tracking a blank point on the sky at the declination of NGC 4278 for 4 minutes, then tracking the galaxy itself for 4 minutes.

The H I signal seen from NGC 4278 is a wide line of low amplitude; since this type of line profile may be mimicked or obscured by baseline fluctuations of various kinds (which, rather than the random channel-to-channel noise, are the true limiting factor in observations of broad-band spectral-line emission from galaxies), we observed adjacent blank parts of the sky with a procedure identical to that used for NGC 4278. We also carried out observations of NGC 4278 with the observing frequency changed to correspond to different central velocities.

NGC 4278 lies in a small group of galaxies (see Fig. 2) and has the following near neighbors: NGC 4274 (Sa, $v_{\rm opt} = 767$ [de Vaucouleurs and de Vaucouleurs 1964]; Krumm and Salpeter 1976 find a 21 cm velocity $v = 926$), NGC 4283 (E0, $v_{\rm opt} = 1085$), and NGC 4286 (S0, v unknown). NGC 4278 is of type E1 and has an optically determined velocity of +630 km s^{-1} (de Vaucouleurs and de Vaucouleurs 1964). Because of the proximity of companions, we carried out observations to check whether the detected emission comes from NGC 4274 or NGC 4286. The individual observations are described more fully

[1] Operated by Associated Universities, Inc., under contract with the National Science Foundation.

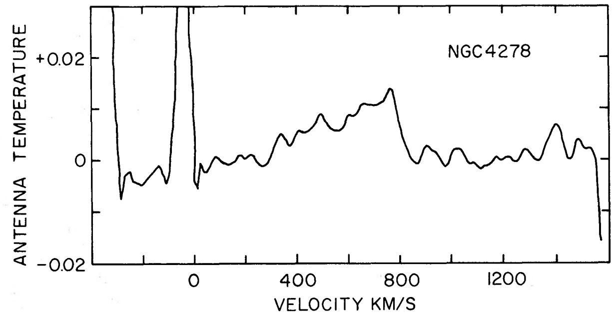

FIG. 1.—H I emission feature from NGC 4278 as observed with the NRAO 43 m telescope. The ends of the plot have been affected by the bad end-channels of the autocorrelator, and the feature near velocity 0 is due to local galactic H I. The data have been smoothed with a 33 km s^{-1} rectangle, and a linear baseline has been removed. The shape of the line is partially obscured by a spurious instrumental feature near 700 km s^{-1}.

below and are summarized in Table 1. The line profiles shown in Figures 3–7 are displayed in terms of antenna temperature (T_A, in K) versus heliocentric velocity, calculated according to the "optical" convention, viz., $v = c\Delta\lambda/\lambda_0$. None of the profiles has been smoothed in any way, and only the final averaged profile (Fig. 7) has had a linear baseline removed from it.

In Figures 3 and 4 we show the combined data of 2 successive days' observation of NGC 4278, centered at $v = +630$. In Figure 3 the contents of the individual receivers (A and B) are shown (these represent essentially independent observations); in Figure 4 the contents of A and B are averaged. Figure 5 shows the average of 2 days' data on adjacent blank sky. These data actually represent one observation of NGC 4286 and one of a point 10′ north of NGC 4278. The first observation was made to check whether a large signal from NGC 4286 (type S0) is responsible for the signal seen at the position of NGC 4278; the second was made to check whether the H I detected in NGC 4278 is actually part of a bridge between it and NGC 4274 (SBa) to the north. (The emission from NGC 4274 itself lies between 700 and 1100 km s^{-1} and has the classic straight-sided line profile seen from a rotating H I disk [Krumm and Salpeter 1976].) No H I was seen at either of these positions; the combined profile also shows no signal. (The slight ripple in the profile is due to ripple in the A receiver observation of NGC 4286.) In Figure 6 we show an observation toward NGC 4278 with the receiver velocity centered on +850 km s^{-1}. Finally, in Figure 7, 3 days' observations of NGC 4278 are combined, and a linear baseline has been removed. The noisy data at either end of the bandpass are due to the bad end-channels of the correlator, some internal narrow-band interference, and galactic H I emission.

Since NGC 4278 is also a moderately strong continuum source (0.5 Jy at 21 cm, Heeschen 1968), there remains the possibility that the line feature is actually caused by baseline curvature due to waves standing between the vertex of the dish and the feed support structure. This effect is unlikely, however, because the

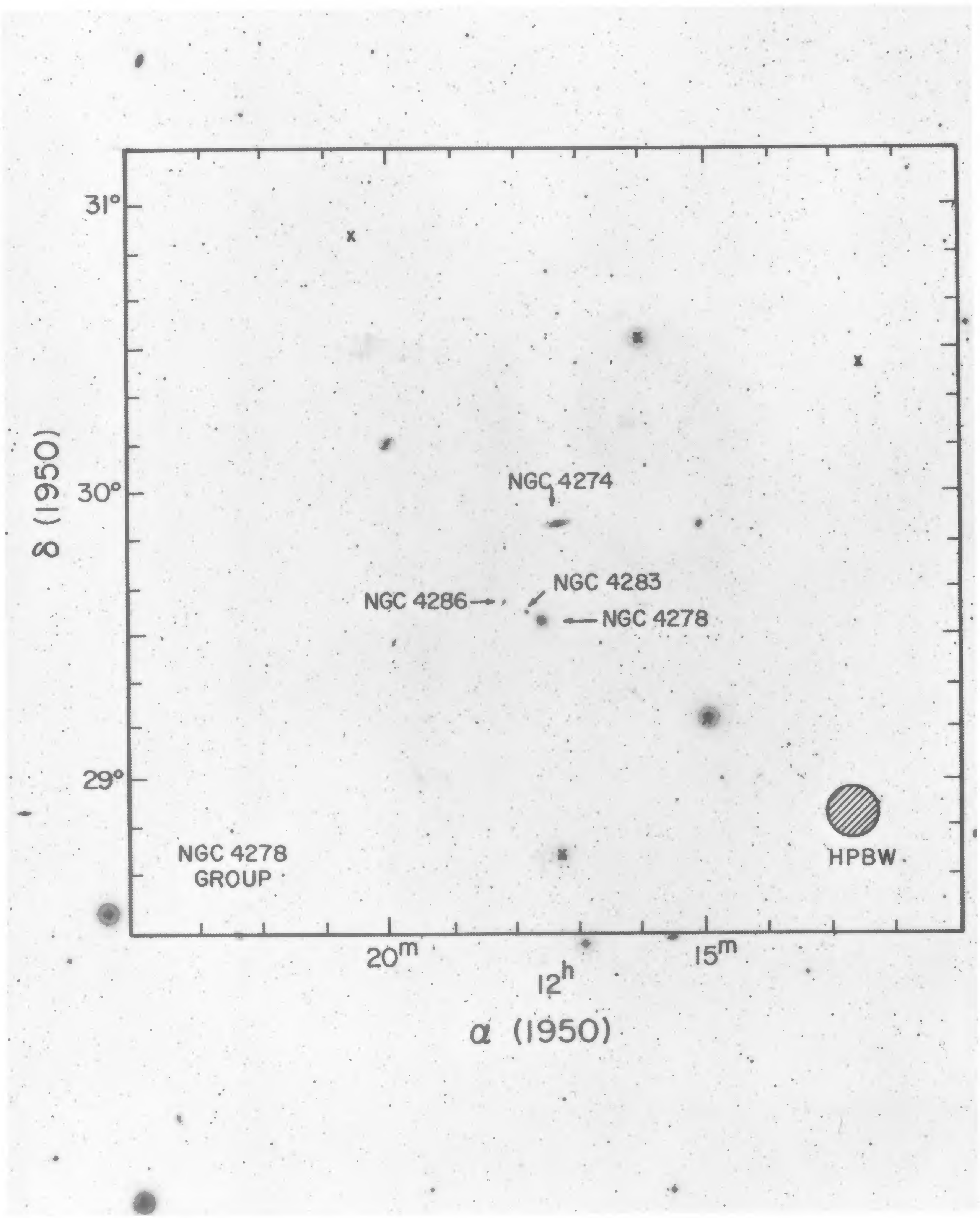

FIG. 2.—The field of NGC 4278 is shown on an enlargement of the National Geographic Palomar Sky Survey (© by the National Geographic Society–Palomar Observatory Sky Survey; reproduced by permission of the Hale Observatories). The half-power beamwidth of the 91 m telescope is shown.

TABLE 1

JOURNAL OF 91 METER OBSERVATIONS

Date	Observation	Remarks
May 2.......	On NGC 4278, $v_c = +630$	Flat baselines, emission evident in both receivers.
May 3.......	On NGC 4278, $v_c = +630$	Flat baselines, emission evident in both receivers.
May 4.......	On NGC 4286, $v_c = +630$	A with sine-wave baseline, B flat, no emission apparent.
May 5.......	10′ N of NGC 4278, $v_c = +630$	Flat baselines, no emission apparent.
May 6.......	On NGC 4278, $v_c = +850$	A bad, B flat.
May 7.......	On NGC 4278, $v_c = +850$	Flat baselines, emission in both receivers.
May 8.......	On NGC 4278, $v_c = +430$	A bad, B flat, emission seen.
May 9.......	On NGC 4278, $v_c = +430$	A bad, B flat, emission seen.
May 9.......	Blank sky, same δ as NGC 4278	A bad, B flat.
May 9.......	5 blank sky points, same δ as 4278, between $\alpha \sim 16^h$ and 16^h45^m	No bump similar to observations on NGC 4278 seen. Mostly flat baselines, some standing waves.

line has the same position and width in observations from the two telescopes, on which the standing-wave pattern should be quite different. Additional evidence which is suggestive but weaker in nature is provided by the fact that the observed signal is the same in both polarizations, whereas the standing-wave pattern is often seen to be different in the two polarizations.

For the reasons stated above, we believe our data give convincing evidence for the detection of H I emission from NGC 4278. The line profile in Figure 7 has a roughly Gaussian appearance, and we have determined its width and central velocity by fitting a Gaussian to it. The results of the 43 m and 91 m observations are summarized in Table 2, where the errors quoted for the 91 m results are the estimated errors of the fit. Basic parameters of the line derived from the 43 m and 91 m data are in reasonable agreement, and the closeness of the radial velocities

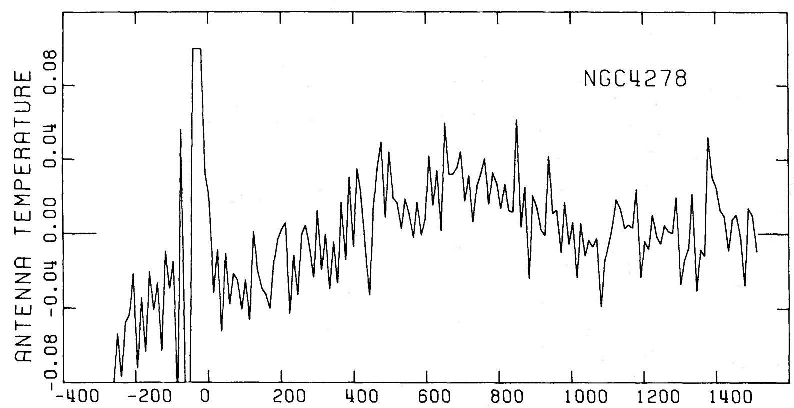

FIG. 3*a*.—Shows combined data from 2 days' observation on NGC 4278 for receiver A

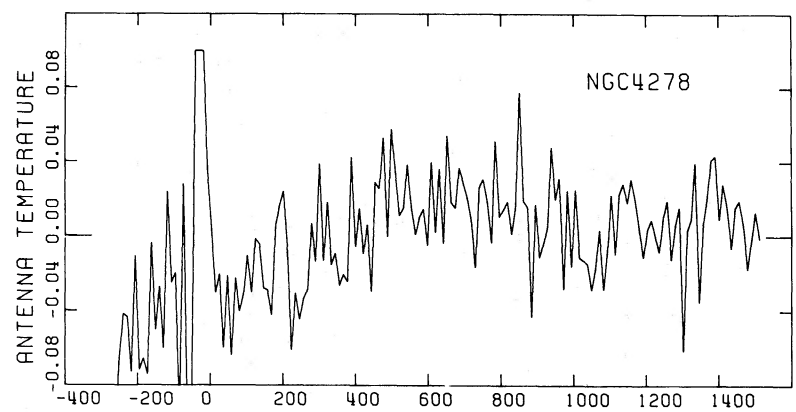

FIG. 3*b*.—Same as *a* but for receiver B

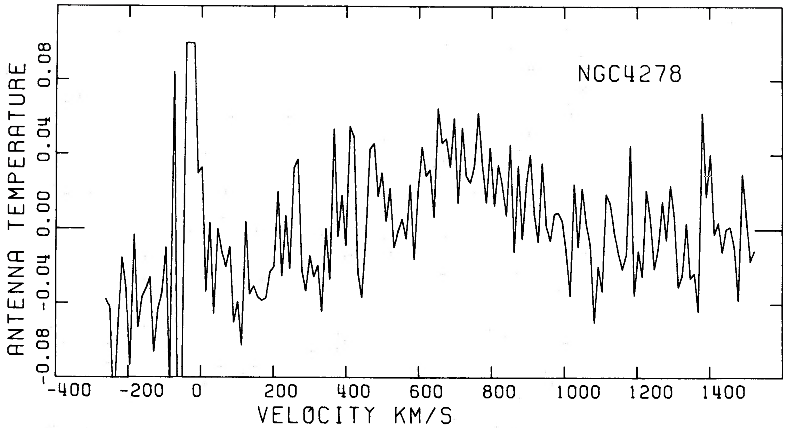

FIG. 4.—Contents of receivers A and B as shown in Fig. 3 are averaged. There has been no smoothing, and no baseline has been removed.

determined by optical and radio measurements clearly establishes the association of the H I with the galaxy. The H I mass was calculated from

$$M_{\mathrm{H\,I}} = 2.36 \times 10^5 D^2 \sum S(\nu)dv \qquad (1)$$

(e.g., Shostak, Roberts, and Peterson 1975), where $\sum S(\nu)dv$ is the integrated line flux in Jy km s^{-1} and D is the distance in Mpc. The 91 m telescope has an efficiency of 1.2 K per Jy. Equation (1) assumes that the source size is much smaller than the beam size. Taking $D = 16$ Mpc (see below), we find $M_{\mathrm{H\,I}} = 7 \times 10^8\ M_\odot$, which corresponds to $N_{\mathrm{H\,I}} = 5 \times 10^{19}$ cm^{-2} for a source filling the antenna beam. The detection of H I in this elliptical has recently been confirmed by observations with the Arecibo 305 m telescope (Knapp, Kerr, and Williams 1977).

As well as providing a positive measurement of H I in a normal elliptical, our data also illustrate the difficulty of detecting H I in elliptical galaxies. If the profile in Figure 7 had been as little as 30% wider with the same area, our detection would probably not have been convincing. It is therefore possible that H I emission from many elliptical galaxies could have a velocity width that is large enough to make the line virtually undetectable with presently available equipment. This is especially true since most previous studies have concentrated on very luminous (and hence massive) galaxies, and the measured velocity dispersions for such massive galaxies (e.g., NGC 4472) can be as much as ~50% larger than in NGC 4278 (Faber and Jackson 1976; Sargent *et al.* 1977). If H I line width correlates with the stellar velocity dispersion, then published upper limits for H I masses may be optimistically low in many cases.

III. DISCUSSION

a) H I *Content and* $M_{\mathrm{H\,I}}/L_{\mathrm{pg}}$

NGC 4278 is a member of de Vaucouleurs's (1975) group 13 and Turner and Gott's (1976) group 53. For either listing of group membership, the mean group velocity is near 800 km s^{-1}. With $H_0 = 50$ km s^{-1} Mpc^{-1}, the distance $D = 16$ Mpc. The photographic absolute magnitude is then $M_{\mathrm{pg}} = -20.0$ ($L_{\mathrm{pg}} = 1.3 \times 10^{10}\ L_\odot$), where we have corrected Holmberg's photographic magnitude for galactic extinction by assuming $A_B = 0.13 \csc |b|$.

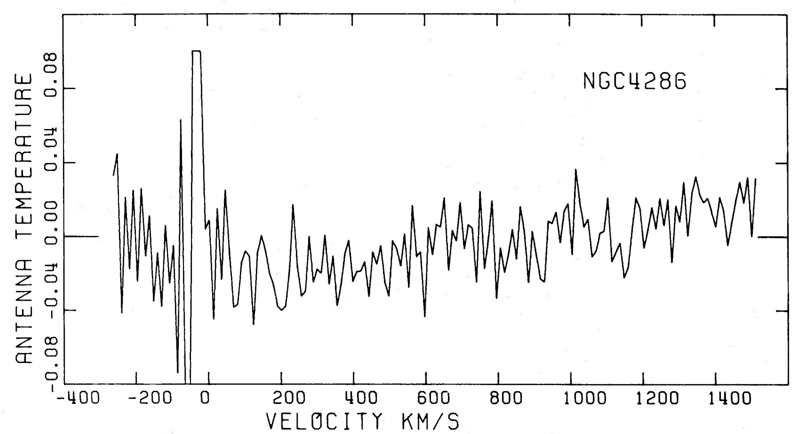

FIG. 5.—Average of 2 days' observation on blank sky adjacent to NGC 4278

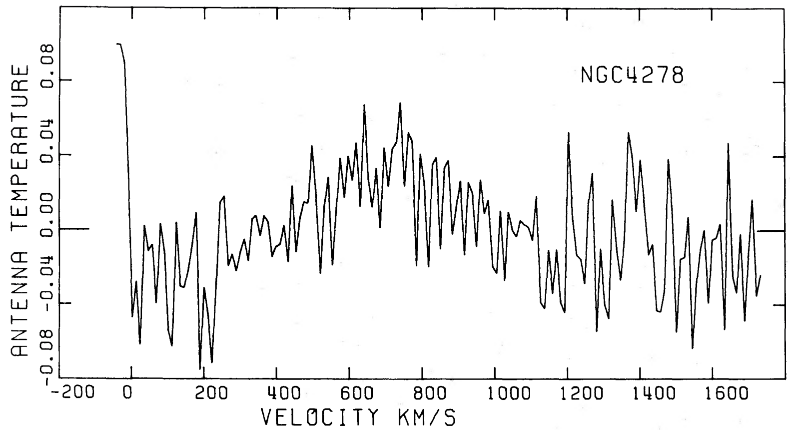

FIG. 6.—Combined observations of receivers A and B for 1 day's data with the center velocity of the bandpass shifted to 850 km s^{-1}. The velocity of the observed feature remains constant.

The distance-independent ratio $M_{\mathrm{H\,I}}/L_{\mathrm{pg}}$ is 0.05 (in solar units), a value which is large compared to upper limits which have been set for many other elliptical galaxies (e.g., the nominal upper limit to $M_{\mathrm{H\,I}}/L_{\mathrm{pg}}$ for NGC 4472 is only 0.002 [Knapp and Kerr 1974]). A recent survey at Arecibo by Knapp, Kerr, and Williams (1977) obtained even more stringent upper limits for roughly 50 normal elliptical galaxies and confirmed that the amount of H I in NGC 4278 is quite large compared to that in typical ellipticals, in none of which was it detected.

Although the mean neutral gas content of ellipticals is low, the existence of galaxies like NGC 4278 indicates that E galaxies exhibit a large dispersion in $M_{\mathrm{H\,I}}/L_{\mathrm{pg}}$. This result is consistent with the conclusions of Balick, Faber, and Gallagher (1976), who found a large scatter among S0 galaxies, and with the data of Roberts (1969) on later Hubble types, among which the H I content also varies widely. $M_{\mathrm{H\,I}}/L_{\mathrm{pg}}$ for NGC 4278 is only about a factor of 2 lower than that in the most hydrogen-poor Sb spirals, for example.

The anomalously high H I content of NGC 4278 leads us to ask whether other properties of the galaxy might be peculiar as well. As mentioned above, the galaxy is classified as morphologically normal (Sandage 1961; de Vaucouleurs and de Vaucouleurs 1964). To verify this, we have inspected the galaxy on a series of short-exposure plates taken by Hubble and kindly made available by A. R. Sandage. The nuclear light distribution seems basically normal (there is no starlike nucleus; see also Osterbrock 1960), although the profile might possibly be slightly asymmetric, due perhaps to the presence of a small embedded dust cloud. Confirmation of such a cloud, however, awaits further optical observations. In any case, no large-scale distribution of dust, either in filaments or in a disk, is apparent on short- or long-exposure photographs. In this respect, NGC 4278 differs markedly from other ellipticals in which H I has been discovered, for example, NGC 5128 (Roberts 1970), which contains prominent absorption patches.

Although the optical appearance of NGC 4278 is normal, the galaxy is noteworthy for its strong nuclear emission lines (Osterbrock 1960) and the unusually intense, compact nonthermal nuclear radio source mentioned above. Whether or not the strong nuclear

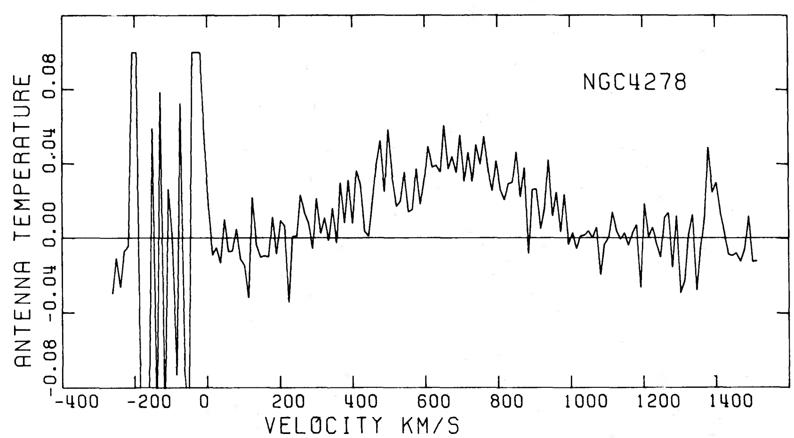

FIG. 7.—All observations of NGC 4278 are combined. The data are not smoothed, but a linear baseline has been removed. The noisy data are due to bad correlator channels; galactic H I; and some internal, narrow-band interference.

TABLE 2

NGC 4278, 21 CENTIMETER LINE CHARACTERISTICS

Parameter	43 m	91 m
S (peak)...........	0.03 ± 0.01 Jy	0.034 ± 0.003 Jy
v_c..................	610 km s^{-1}	670 ± 17 km s^{-1}
Δv................	520 km s^{-1}	470 ± 40 km s^{-1} ($\sigma = 200$ km s^{-1})
$M_{\rm H\,I}$ (D = 16 Mpc)...	$5 \times 10^8 M_\odot$	$7.2 \times 10^8 M_\odot$

activity in NGC 4278 is related in some way to the presence of detectable amounts of H I is not yet known. We discuss this point further below.

Considerable information is available on the stellar content of NGC 4278, all of which indicates that it is normal for an elliptical galaxy of its luminosity. Compared to the colors of ellipticals in the study by de Vaucouleurs and de Vaucouleurs (1972), NGC 4278 differs from the mean by less than 0.01 mag in $B - V$ and -0.05 mag in $U - B$. Ten-color photometry by Faber (1973) also showed it to be normal. Since these observations were made with large apertures, the possibility remains that the nuclear colors are subtly peculiar. However, an absolute spectral scan of the central 10″ of the galaxy from 3000 to 9000 Å obtained by W. L. W. Sargent has been compared with a composite spectrum for normal giant ellipticals derived by Wilkinson (1976). Apart from the presence of emission lines, the spectrum of NGC 4278 shows no abnormalities with regard to either the slope and shape of the stellar continuum or the strength of the stellar absorption lines. Scans with a 9 Å spectral resolution of the central 3″ by Faber also appear normal. In particular, there is no sign of enhanced Balmer absorption, usually a sensitive indicator of young stars. The presence of H I has therefore apparently not given rise to the recent birth of significant numbers of stars with masses greater than $\sim$2–3 $M_\odot$.

In conclusion, apart from its nuclear optical and radio emission, NGC 4278 seems to be a normal elliptical galaxy of moderately high luminosity.

b) *Distribution and Motion of the Gas*

Since the light distribution and stellar content of NGC 4278 are not at all unusual, it is puzzling why this galaxy differs from most other normal elliptical galaxies in having a large neutral-gas content. Where did the gas come from, and what will be its eventual fate? To answer these questions, it is vital to know the spatial distribution and dynamical properties of the gas. The present data are not adequate to discuss these questions fully, but they do yield some important clues.

First, the fact that the H I masses are about the same for the 43 m and 91 m observations shows that the H I distribution is not significantly larger than the 10′ beam of the 91 m telescope. For comparison, the Holmberg (1958) diameter of the galaxy is 6′, and the diameter $D(0)$ from the *Reference Catalogue of Bright Galaxies* (de Vaucouleurs and de Vaucouleurs 1964) is 1′.8.

Second, the line profile in Figure 7 is, to our knowledge, unlike any H I profile previously observed in a galaxy. Its approximately Gaussian shape is very different from the steep-sided, double-peaked profiles seen in spiral and most S0 galaxies, which are due to a disk of gas in circular motion with a relatively flat rotation curve. Face-on disk galaxies, irregulars, and some nuclear regions of early-type spirals have Gaussian-like profiles with relatively small widths (less than 100 km s^{-1}), which probably result from random gas motions (e.g., Fisher and Tully 1975; Krumm and Salpeter 1976), but the profile of NGC 4278 is much wider than those found in these objects. Thus, none of these cases seems directly analogous to that of NGC 4278.

The sloping shoulders on the line profile suggest that turbulent motions may be important. The value of the velocity dispersion σ obtained from the best-fitting Gaussian profile is 200 km s^{-1}. As it happens, this value is in exact agreement with the expected line-of-sight velocity dispersion of the stars in an elliptical galaxy of the same luminosity as NGC 4278 (Faber and Jackson 1976, corrected to their absolute magnitude scale). This good agreement reinforces the notion that the gas, like the stars, is moving in the gravitational potential well of NGC 4278 and that the association between the gas and the galaxy is not a transitory phenomenon.

The suggestion that turbulent motions are important may be related to Osterbrock's finding that the nuclear emission-line profiles have large rms widths of $\sim$280 km s^{-1}. It is not clear, however, that the nuclear ionized gas and the neutral H I are mutually associated.

On the other hand, it is conceivable that the gas is actually in a quiescent disk in circular motion and that the shape of the rotation curve is responsible for the line profile. If so, the gas cannot be located in a region where the rotation curve is flat. Provided the mass is distributed like the light, we would expect the circular velocity to decline rather slowly with radius. For example, in the model for NGC 3379 presented by Miller and Prendergast (1962), the circular velocity declines roughly as $r^{-1/4}$ beyond 1 kpc. If the mass-to-light ratio increases with radius, the circular velocity would decline even more slowly; and in actual observations of galaxies dominated by elliptical-like, spheroidal components, rather flat rotation curves are seen (e.g., NGC 4594, Faber *et al.* 1976; NGC 3115, Rubin, Ford, and Peterson 1976). Thus, we would most naturally expect a normal double-peaked profile if the gas is located outside the nucleus beyond, say, 1–2 kpc. This naive expectation does not, of course, agree with the observations.

Before the notion of a quiescent disk in circular motion is discarded, however, it is of interest to inquire as to what sort of rotation curve *would* be consistent with the line shape. Reasonable agreement can be achieved with a uniform-density disk in solid-body rotation. The antenna temperature from such a disk of radius R (seen edge-on with a telescope of beam-width B) is given by:

$$T_A(v) \propto [1 - (v^2/K^2R^2)]^{1/2} \exp\left[\frac{-(4 \ln 2)v^2}{K^2B}\right], \quad (2)$$

where $K \equiv v_c(r)/r$, $v_c(r)$ being the circular velocity at r. If the disk is much smaller than the beam, the profile is half an ellipse; if it is comparable to or larger than the beam, the profile shape is Gaussian. Both of these profiles would be consistent with the observations, although the good agreement between the H I masses found with the 43 m and with the 91 m telescopes suggests that the H I distribution is not a great deal larger than the 10′ beam.

Since solid-body rotation is a possibility, it is interesting that Osterbrock measured solid-body rotation for the nuclear emission disk. His data give $K = 50$ km s^{-1} arcsec^{-1} along the major axis. If the H I were associated with the nuclear emission disk, relation (2) implies that the disk radius $R \approx 8''$. This radius is small compared to the radii of the galaxy given above, which were 1′–3′.

In summary, our data are consistent with several models for the distribution of the gas. The gas could be distributed in a roughly spherical configuration, much like the distribution of stars in the galaxy, or it could be located in a flattened disk in approximately solid-body rotation. The radius of such a disk could be as small as 8″ or as large as the Holmberg radius of the galaxy.

The recent crude mapping of the H I in this galaxy by Knapp, Kerr, and Williams (1977) at Arecibo suggests that this last possibility, a large disk, is correct and, further, that the disk has roughly an east-to-west orientation. Observations at much higher spatial resolution are necessary to understand precisely how the integrated line profile observed with the 91 cm telescope could be produced in such an extended disk, which would seem to require a roughly solid-body rotation curve out to large radii—a circumstance difficult to understand on physical grounds, as we have seen above.

If confirmed by further work, the orientation of this disk may be crucial to understanding the origin of the neutral gas. The east-west elongation of the disk does not agree either with the position angle of the major axis of the galaxy or with the direction of rotation and major axis of the extended nuclear emission (Osterbrock 1960; confirmed by J. Miller, private communication). Both of these have a position angle of roughly 18°. The stars also rotate like the nuclear gas, as seen on J. Miller's spectra. The distribution and motions of both stars and ionized gas are therefore all consistent with a flattened, rotating galaxy with a major axis that is oriented roughly north-to-south, nearly perpendicular to the H I disk. If true, this result would suggest that the angular momentum vector of the neutral gas differs substantially from that of the galaxy itself, and this conclusion would in turn suggest an external origin for the neutral H I. We discuss this point at greater length in the following section.

c) The Origin of the Gas

The mass of gas in NGC 4278 is sufficiently low that it could conceivably have been produced as a result of mass loss from dying stars. Faber and Gallagher (1976) have estimated that the expected influx from this source in a normal elliptical galaxy would be about 0.015 $M_\odot$ yr^{-1} $(10^9 L)^{-1}$ or 0.15 $M_\odot$ yr^{-1} of hydrogen alone in NGC 4278, if the concentration of He is 25% by mass. At this rate, 5×10^9 years would be required to accumulate the observed mass of hydrogen, a period of time comfortably less than the age of the galaxy.

Although the source of supply from dying stars is adequate, several facts do not fit this or other hypotheses based on internal injection. The difference between the angular momentum vectors of the H I and the galaxy has already been mentioned. The large extent of the H I disk is also a problem. Although its diameter is comparable to the Holmberg diameter, the gas distribution is much less concentrated than the starlight. A substantial increase in angular momentum would therefore be necessary to place the gas in orbit at such a large distance from the nucleus. Ejection by a nuclear explosion would meet similar objections as a hypothesis.

The lack of visible dust might also pose a problem since most K giants in normal ellipticals have solar or supersolar abundances (e.g., Faber 1973; Spinrad and Stone 1975), and one might expect a normal gas-to-dust ratio on these grounds. This argument is suggestive but not definitive, however, since the extent of the H I disk is large compared to the well-exposed image on available photographs. Absorbing clouds could therefore exist far from the nucleus and yet escape detection.

Finally, the mass-loss theory does not explain why NGC 4278 differs from other normal elliptical galaxies, in which stars presumably lose mass at similar rates and yet no neutral gas is detected.

Alternatively, the H I could be a primordial remnant left over after the formation of the original galaxy. Here again, however, it is not clear why NGC 4278 differs from other normal ellipticals, in which the original episode of star formation was very efficient and/or the leftover gas was swept out early by a galactic wind (Larson 1974). We might also expect a small fossil stellar disk to be present, which apparently is not the case. Further, the angular momentum discrepancy would require that the material making up the present disk be dynamically distinct from the gas which formed the parent galaxy. While not inconceivable, this additional requirement does not flow naturally from the hypothesis and must be tacked on in an ad hoc fashion. In summary, we feel that all theories founded on an internal origin for the gas suffer from serious, and perhaps fatal, drawbacks.

Infall models, on the other hand, seem to have fewer problems. Angular momentum would not present a difficulty for any of the possible gas distributions we have discussed. The lack of visible dust is also consistent with the low metal abundance which might plausibly exist in unprocessed intergalactic gas. Continuous infall from a generalized intergalactic medium would conflict with the apparent uniqueness of NGC 4278, while the large difference in velocity of greater than or equal to 250 km s^{-1} between NGC 4274 and 4278 would argue against tidal accretion from the spiral companion. Capture of an isolated intergalactic gas cloud, however, remains a possibility. Such clouds are thought to exist in other groups of galaxies; for example, Mathewson, Cleary, and Murray (1975) have found several intergalactic H I clouds in the Sculptor group with masses of 10^8–10^9 $M_\odot$. Since capture of a substantial mass of gas by an empty galaxy is probably uncommon, we would expect galaxies like NGC 4278 to occur infrequently. Thus, the capture theory is consistent with available data, but—because it explains NGC 4278 by what must be considered a chance occurrence—this theory, too, is rather ad hoc in nature.

Finally, it should be emphasized that much of the argument in this section depends heavily on the preliminary Arecibo mapping data, which must be confirmed by future observations at higher spatial resolution.

d) *Evolution*

Regardless of the origin of the gas, it is tempting to speculate that NGC 4278 will not long remain in its present state. If turbulent motions are large, collisions will dissipate the turbulent energy, producing a relatively cold disk which might become unstable to star formation. The end result would be a weak stellar disk embedded in the halo component. Intermediate evolutionary phases could be quite striking, and objects like NGC 5128 (Cen A) and NGC 4594 (the Sombrero) might represent different stages in the lifetime of such an object. Related ideas have been advanced by Larson (1976) and by van den Bergh (1972*b*). While this possibility is far from proven at this time, the existence of sizable amounts of gas in NGC 4278 could be of great importance to our understanding of what factors determine the morphological type of a galaxy and whether galaxies significantly change in structure over a time which is short compared with the age of the universe.

IV. SUMMARY AND CONCLUSIONS

NGC 4278 is an E1 galaxy which is normal in terms of its appearance on photographs and its stellar content as determined from *UBV* colors and spectrophotometry of the nuclear region. However, unlike other elliptical galaxies, it contains a substantial interstellar medium; we have measured an H I mass of 7×10^8 $M_\odot$, which gives $M_{\rm H\,I}/L_{\rm pg} = 0.05$. Since no other normal elliptical has yet been detected in 21 cm, H I emission, NGC 4278 stands out from other elliptical galaxies and is probably near the upper limit of hydrogen content for the E class.

The H I line profile is approximately Gaussian in shape with a FWHM of 470 km s^{-1} centered near the optical radial velocity of 640 km s^{-1}. This profile is unlike those observed in galaxies with disks, and the usual picture of H I rotating in a ring with a small velocity gradient does not apply. The data presented here are consistent with a wide range of possible models, including randomly moving clouds, a turbulent disk, or a quiescent disk in roughly solid-body rotation. However, preliminary results by Knapp, Kerr, and Williams (1977) suggest that the H I is concentrated in an extended, rotating disk oriented in the east-west direction—nearly orthogonal to the optical major axis of the galaxy and the axis of the ionized gas, as determined from velocity gradients. Because this result is so puzzling, we are reluctant to conclude that the gas distribution is definitely known at this time. An interferometer map is clearly needed to disentangle the possibly complex structure of the H I.

The interstellar gas in NGC 4278 is remarkably quiescent. There is no evidence for recent star formation; and with the possible exception of a small cloud near the nucleus, dust is not seen on optical photographs. The absence of visible dust might be a weak argument for a low abundance of heavy elements.

It is a tantalizing possibility that the H I in NGC 4278 did not come from within the galaxy. Most of the possible gas distributions, the apparent uniqueness of NGC 4278, and the lack of interstellar dust are incompatible with an internal origin. Perhaps an intergalactic gas cloud, of the type which may exist in groups of galaxies, has been captured. Such a cloud might have low heavy-element abundances and could fit any of the distribution models. If it can be established beyond doubt that the gas is in a disk which is perpendicular to the major axis of the galaxy, capture would become by far the most likely source of gas.

Perhaps NGC 4278 is in a transitory stage and will evolve into a rather different object as turbulent motions in the gas die out and stars eventually form. It is a provocative possibility that NGC 4278 will change its morphological type through the production of a disk of young stars.

Further understanding of the NGC 4278 phenomenon will require careful observations of the spatial distribution and physical characteristics of both the H I and optical emission. Only then can fundamental questions on the origin of the gas and its possible connection with the nuclear activity be answered with certainty. Such a program might also allow us, for the first time, to measure the mass distribution of a pure spheroidal galaxy well outside the nuclear region.

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Note added in proof.—Since this paper was written, H I in NGC 4278 has also been detected by Bottinelli and Gouguenheim (1977, *Astr. Ap.*, **54**, 641), who obtained a very similar value for the total H I mass.

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