

H I OBSERVATIONS OF HIGH-LUMINOSITY ELLIPTICAL GALAXIES

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ABSTRACT

Sensitive 21-cm line observations were made with large velocity coverage towards eight luminous early-type galaxies in a search for possible H I emission with a large velocity width. Only one object, the tidally interacting pair of S0's NGC 4105/4106, was detected, with $M(\text{H I})/L_B = 0.05 M_\odot/L_\odot$. Previously published detections of H I in three ellipticals (NGC 2974, 3904, and 3962) were not confirmed. Low limits on the H I content of the luminous ellipticals NGC 4472 and NGC 5322 were set; with assumed linewidths of 1100 km/s, we find $M(\text{H I})/L_B \lesssim 0.005$ and $\lesssim 0.04 M_\odot/L_\odot$, respectively.

I. INTRODUCTION

This paper discusses sensitive H I line observations made with wide velocity coverage of a small sample of high-luminosity early-type galaxies. The H I content of such galaxies is of interest in studies of galactic evolution, in considerations of the possible relationship between the presence of cold gas and nuclear activity in bulge-dominated galaxies, and because the presence of gas with observable kinematic properties provides a probe of the large-scale mass distribution of the galaxy. Recent summaries of the status of ideas on these subjects are given by Sanders (1980), Hummel (1980), and Dresel, Bania, and O'Connell (1982).

The present paper discusses observations made with the National Radio Astronomy Observatory's new Mark IV autocorrelator and FET L-band receiver, which together provide much wider bandwidths (yet adequate velocity resolution) than have previously been available for H I line observations. The use of a large bandwidth is important for observations of large galaxies because the H I signals, if any, are very weak and can be mimicked by nonflat base lines; the use of large bandwidths allows the frequency behavior of the instrument to be evaluated. Further, the most luminous galaxies could produce emission lines too wide to be observed at all with the previously available 10-MHz bandwidth (cf. the values for the one-dimensional stellar velocity dispersion σ_* found for these systems—Tonry and Davis 1981a).

The small sample of galaxies observed herein includes two edge-on S0 galaxies (NGC 4762 and 5866), one tidally interacting pair (NGC 4105 and 4106), and five high-luminosity ellipticals (NGC 2974, 3904, 3962, 4472, and 5322). Of the ellipticals, detections of H I have been claimed in the first three, and also in NGC 4105/6 (Bottinelli and Gouguenheim 1977, 1979a,b; Huchtmeier, Tammann, and Wendker 1977). In the present work H I was detected from only one object, the close pair NGC 4105/6. The observations are described in Sec. II, and the results summarized and briefly discussed in Sec. III.

II. THE OBSERVATIONS

The observations were made in May 1982 at the National Radio Astronomy Observatory, Green Bank, West Virginia, using the 43-m telescope, a dual-polarization cooled FET L-band amplifier front end, and the Mark IV 1024-channel autocorrelation spectral line receiver. The correlator was used in its parallel mode, with one bank of 512 channels detecting each polarization. The system temperature for each receiver was about 50 K throughout the observing period, and all of the observations were made with a bandwidth of 40 MHz, giving a total usable velocity coverage of $\gtrsim 7000$ km/s, a channel spacing of 16.5 km/s, and a velocity resolution of ~ 20 km/s. The three-level correlation used in the spectrometer resulted in a degradation of the signal-to-noise ratio due to clipping of about 10%. The observing frequency was centered on that corresponding to the optically measured velocity of the galaxy, and the velocities calculated according to the conventions used in optical observations (heliocentric radial velocities, with $V = c\Delta\lambda/\lambda_0$). The observations were made by position switching between the galaxy and a reference sky position chosen so that the telescope followed the same altitude-azimuth track for both signal and reference observations. An integration time of two minutes was used, and the reference position was offset by 2^m30^s (or 38 arcmin near the equator, about twice the telescope half-power beamwidth of 21 arcmin at this frequency) from that of the galaxy. As a result of this procedure and the extreme stability of the front-end receiver, the base lines for almost all of the observations were flat to much better than the rms channel-to-channel noise across the entire velocity range. The exceptions were observations made near sunset, which had base line ripple and were discarded. Some observations were affected by sporadic interference (which even if at a low level was usually immediately obvious because it was strongly polarized) and had to be discarded. In all, about 60% of the data gathered were usable. The good observations were summed for each galaxy and a linear base line, fitted to the regions of the spectrum free of emission and interfer-

ence, removed from each averaged observation. The flux scales were calibrated relative to that of 3C 286, whose flux at 1420 MHz was taken as 14.7 Jy (Baars *et al.* 1977); the efficiency of the telescope was found to be $S/T_A = 3.9$ Jy/K.

Apart from preliminary test observations of spiral galaxies with known H I emission, a total of eight objects, those listed in Sec. I, was observed. The results are summarized in Table I, where we give: the name of the galaxy; the morphological type; the heliocentric velocity (from de Vaucouleurs, de Vaucouleurs, and Corwin 1976, hereafter referred to as SRCBG; Tonry and Davis 1981a; or Sandage and Tammann 1981, hereafter referred to as RSA); the distance in Mpc [calculated from the heliocentric velocity corrected for the motions of the Galaxy and the Local Group, with an assumed value of $H_0 = 75$ km s Mpc⁻¹. For galaxies in the Virgo cluster, Tonry and Davis' (1981a) distance of 14.5 Mpc was assumed]; and the blue luminosity L_B in L_\odot , calculated from the B_T values in the SRCBG or the RSA according to the recipes of Faber and Gallagher (1979). Next in Table I are given the H I results; the rms noise in mJy, calculated from the line profiles after smoothing to a velocity resolution of ~ 80 km/s; the expected H I linewidth ΔV in km/s; and the upper limit on the integrated H I flux, on the H I mass in M_\odot , and on $M(\text{H I})/L_B$. For NGC 4105/6, the observed values of these quantities are given.

The estimates of ΔV are "worst case" estimates. That is, the assumption is made that the H I is distributed in a disk edge-on to the line of sight (this assumption being appropriate for NGC 4762 and 5866, both edge-on S0 galaxies). If we assume that the velocity dispersion σ_v in an elliptical galaxy is isotropic and that the mass of the system is dominated by a spherical r^{-2} halo, then the circular velocity is $V_c \sim \sqrt{3}\sigma_v$. (cf. Gunn 1981), so we estimate ΔV to be $2\sqrt{3}\sigma_v$, where the values of σ_v are given directly by Tonry and Davis (1981a) or Kormendy and Illingworth (1982), or are estimated from the L_B -vs- σ_v relationship as calibrated by Tonry and Davis (1981b).

For each of NGC 2974, 3904, and 3962, limits are calculated for two values of ΔV : those found as above, and those given for the H I profiles for these galaxies (Bottinelli and Gouguenheim 1977, 1979a,b). The upper limits on the line flux are calculated assuming that the signal is less than three times the rms noise over the appropriate velocity interval.

III. DISCUSSION AND CONCLUSIONS

a) NGC 2974, NGC 3904, and NGC 3962

H I, in amount a few $\times (10^8 - 10^9) M_\odot$, has been suggested to be present in the following galaxies: in NGC 2974 by Bottinelli and Gouguenheim (1979a), in NGC 3904 by Bottinelli and Gouguenheim (1977), and in NGC 3962 by Bottinelli and Gouguenheim (1979b). Observations from the present paper are given in Fig. 1; also shown are the strengths of the signals found by the above authors. NGC 3962 was mapped by the above authors; emission was found at roughly equal strength at points on the galaxy and 4 arcmin east and west of it. The strength of the spatially integrated signal, as would be seen by the larger beamwidth of the 43-m telescope, is also shown in Fig. 1.

Figure 1 shows that we probably detected none of these galaxies. For NGC 2974, our sensitivity is not quite good enough to be conclusive and we can only say that our upper limit is comparable to the signal claimed by Bottinelli and Gouguenheim (1979a). A somewhat lower limit than ours is found for NGC 3962 by Huchtmeier, Tammann, and Wendker (1977), who claim $S < 4$ mJy for this galaxy.

b) NGC 4105/4106

Weak H I emission was detected from this pair of interacting S0's (so classified in the RSA), and the observed profile is shown in Fig. 2; it bears a reasonable resemblance to those published by Bottinelli and Gouguenheim (1979a), and Huchtmeier, Tammann, and Wendker (1977). The two peaks agree roughly in veloc-

TABLE I. H I Observations of high-luminosity elliptical galaxies.

Galaxy	Type	V_H	D (Mpc)	L_B/L_\odot	$S_{\text{rms}}(\text{H I})$ (mJy)	$\Delta V(\text{H I})$ (km s ⁻¹)	$\Sigma S \Delta V$ (Jy km s ⁻¹)	$M_{\text{H I}}$ (M_\odot)	$M_{\text{H I}}/L_B$
N2974	E4	1998	24	1.96×10^{10}	3	{255 ^a 850	<2.3 <7.6	< 3.1×10^8 < 1.0×10^9	<0.016 <0.053
N3904	E2	1613	18	9.34×10^9	3	{490 ^a 720	<4.4 <6.5	< 3.4×10^8 < 4.9×10^8	<0.036 <0.053
N3962	E1	1822	22	1.89×10^{10}	5	{346 ^a 840	<5.2 <12.6	< 5.9×10^8 < 1.4×10^9	<0.031 <0.076
{N4105 N4106	{S0 S0/a	{1906 2182}	24	1.77×10^{10} 1.14×10^{10}	5	760 \pm 300	11.7	1.53×10^9	0.053
N4472	E2	995	14.5	6.23×10^{10}	1.9	1100	<6.3	< 3.1×10^8	<0.005
N4762	S0	937	14.5	1.76×10^{10}	19	760	<43.3	< 2.1×10^9	<0.122
N5322	E3	1902	27	5.32×10^{10}	4	1060	<12.7	< 2.2×10^9	<0.041
N5866	S0	692	12	1.06×10^{10}	6	510	<3.1	< 1.0×10^8	<0.010

^a From Bottinelli and Gouguenheim (1977, 1979a, b).

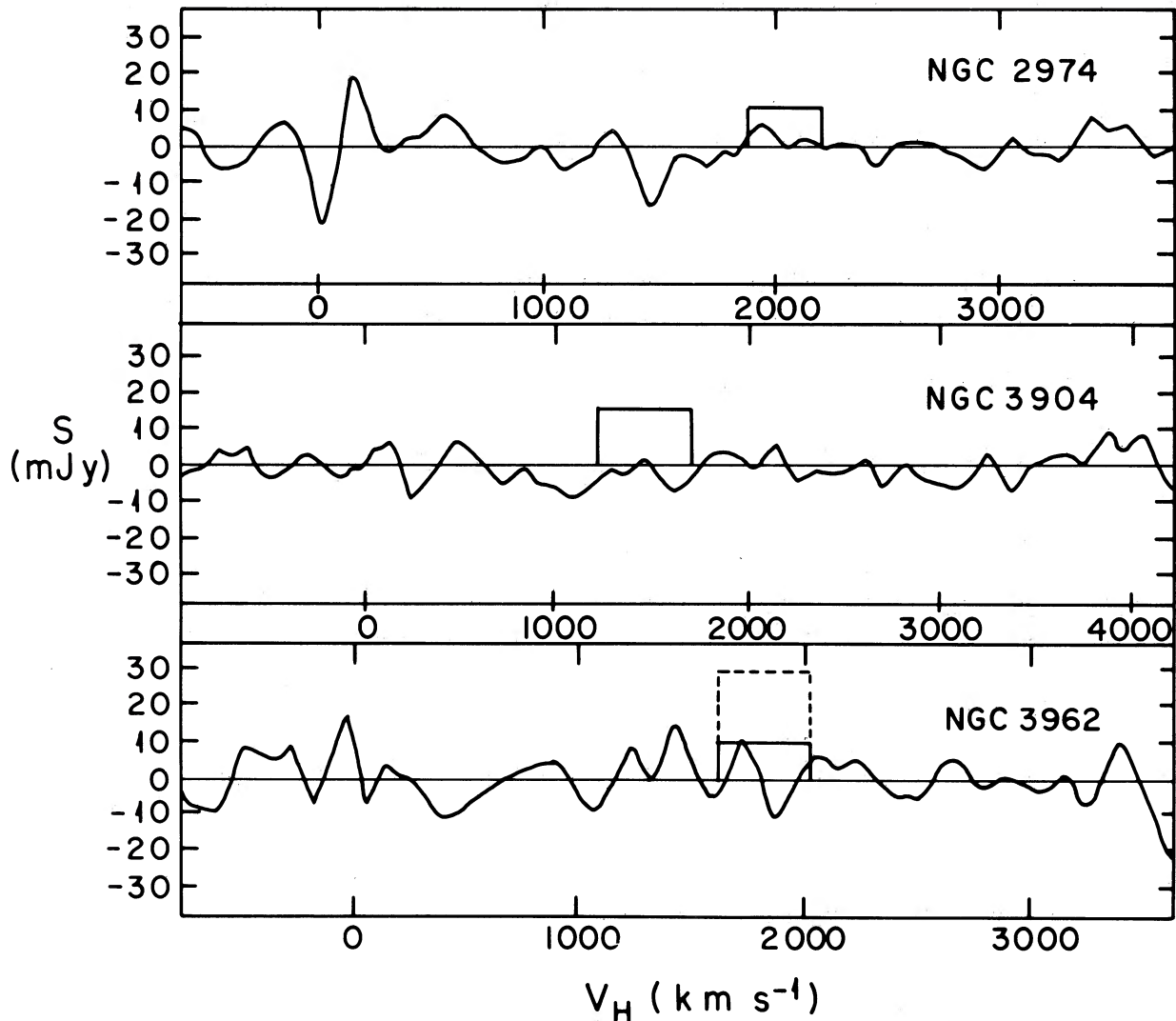


FIG. 1. H I observations of NGC 2974, 3904, and 3962, made with a velocity resolution of ~ 80 km/s. The strength and velocity extent of the H I signals observed by Bottinelli and Gouguenheim (1977, 1979a,b) are shown (see text).

ity with the velocities of the galaxies as measured by Martin (1976) but in view of the tidal interaction between the pair and the large dispersion of the H I profile, it is more likely that the H I emission profile reflects the velocities of gas involved in the interaction (cf. similar line profiles found for other interacting systems by Gallagher *et al.* 1981). The mean velocity of the H I is 1940 ± 150 km/s.

c) NGC 4472 and NGC 5322

These are the most luminous galaxies in the present work. The observation of NGC 4472 is shown in Fig. 3, together with the maximum expected velocity extent of any associated H I. The limit on $M(\text{H I})/L_B$ (0.005) for this galaxy is lower than most upper limits on the gas content of galaxies and a factor of 2 lower than the H I

content of NGC 4594 (Faber *et al.* 1977). It is possible that any H I is in a distribution much larger than the telescope beamwidth [which is 90 kpc at the distance of the Virgo cluster; the diameter of the galaxy is $D_{25} = 37$ kpc (SCRBG)]. The limit for NGC 5322 is also quite small, and, since this galaxy is fairly far away, it is unlikely that any H I has been missed in our observations; the telescope beamwidth is 160 kpc at the distance of NGC 5322.

The present preliminary observations illustrate the power of the new NRAO instrumentation for making sensitive wideband H I line observations of galaxies. No further detections have been made; a large-scale survey with a larger telescope is needed. The present observations probably reduce the number of bona fide ellipticals in which H I emission is seen. At the moment, good detections are available for only four: NGC 1052 (Knapp

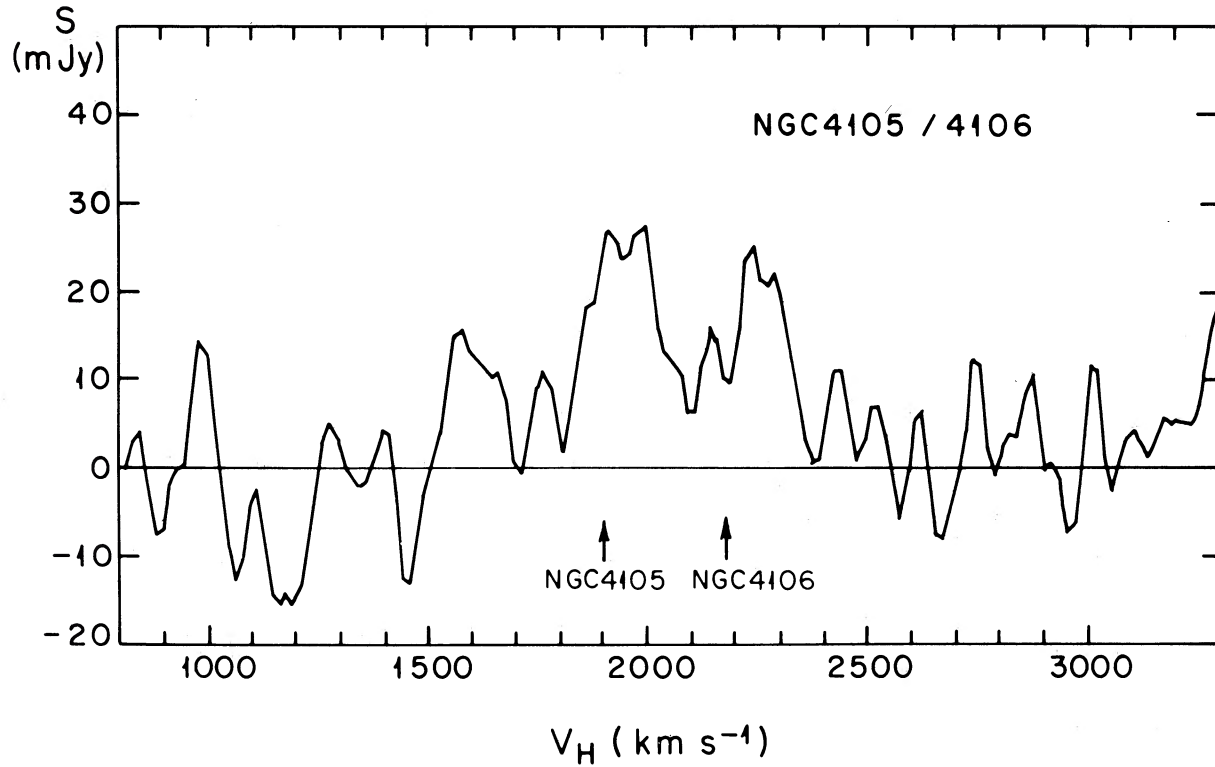


FIG. 2. H I profile observed towards the tidally interacting pair NGC 4105 (S0) and NGC 4106 (S0/a) with a velocity resolution of ~ 40 km/s. The optically measured radial velocities of the two galaxies are shown (Martin 1976).

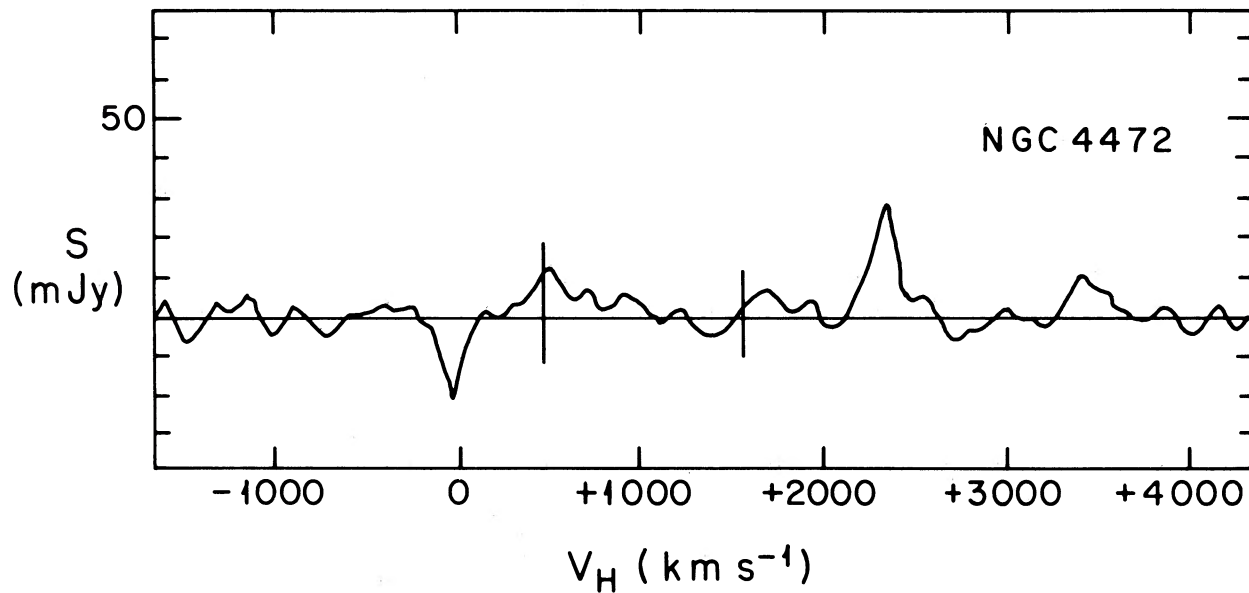


FIG. 3. H I observation of NGC 4472, with a velocity resolution of ~ 80 km/s. The dip near 0 km/s is due to Galactic H I; the bump near 2300 km/s to low-level intermittent interference. The vertical lines represent the maximum expected velocity range of 1100 km/s (see text).

et al. 1978); NGC 4278 (Gallagher *et al.* 1977); UGC 01053 (Haynes and Giovanelli 1980); and UGC 09114 (Dressel *et al.* 1982).

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