EXTENDED H I DISKS IN DUST LANE ELLIPTICAL GALAXIES

THOMAS A. OOSTERLOO AND RAFFAELLA MORGANTI
ASTRON, Postbus 2, NL-7990 AA Dwingeloo, Netherlands; oosterloo@astron.nl, morganti@astron.nl

ELAINE M. SADLER
School of Physics, University of Sydney, NSW 2006, Australia; ems@physics.usyd.edu.au

DANIELA VERSANI
Dipartimento di Astronomia, Università di Bologna, via Zamboni 33, I-40126 Bologna, Italy

AND

NELSON CALDWELL
Smithsonian Astrophysical Observatory and Steward Observatory, 949 North Cherry Avenue, Tucson, AZ 85719; baldwell@fwo99.sao.arizona.edu

Received 2001 August 11; accepted 2001 October 22

ABSTRACT

We present the results of H i observations of five dust lane elliptical galaxies with the Australia Telescope Compact Array. Two galaxies (NGC 3108 and NGC 1947) are detected, and sensitive upper limits are obtained for the other three. In the two detected galaxies, the H i is distributed in a regular, extended, and warped disklike structure of low surface brightness. Adding data from the literature, we find that several more dust lane elliptical galaxies have regular H i structures. This H i is likely to be a remnant of accretions and/or mergers that took place a considerable time ago and in which a significant fraction of the gas survived to form a disk. The presence of regular H i structures suggests that some mergers lead to galaxies with extended low surface brightness density gas disks. These gas disks will evolve very slowly, and these elliptical galaxies will remain gas-rich for a long period of time. One of the galaxies we observed (NGC 3108) has a very large amount of neutral hydrogen ($M_{HI} = 4.5 \times 10^9 M_\odot$; $M_{HI}/L_B \sim 0.09$), which is very regularly distributed in an annulus extending to a radius of $\sim 6 R_eff$. The kinematics of the H i distribution suggest that the rotation curve of NGC 3108 is flat out to at least the last observed point. We estimate a mass-to-light ratio of $M/L_B \sim 18 M_\odot/L_B, \odot$ at a radius of $\sim 6 R_eff$ from the center. Several of the galaxies we observed have an unusually low gas-to-dust ratio $M_{HI}/M_{dust}$, suggesting that their cold interstellar medium, if present as expected from the presence of dust, may be mainly in molecular rather than atomic form.

Key words: galaxies: individual (NGC 1947, NGC 3108, NGC 7049, NGC 7070A, ESO 263-G48) — galaxies: ISM — galaxies: kinematics and dynamics

1. INTRODUCTION

Theoretical models of galaxy formation and evolution have pointed out that differences between gas content and gas supply are key factors in explaining differences between different galaxies (see, e.g., Kauffmann 1996). At the same time, H i, far-infrared (FIR), and CO observations of elliptical galaxies have demonstrated that many of these objects have an active and interesting cold interstellar medium (ISM), often qualitatively similar to that observed in spiral galaxies, although usually (but not always) in much smaller quantity (see Knapp 1999 for a review). The limits in sensitivity of the available instruments is still the main limitation for studying the cold ISM in elliptical galaxies in a detailed and unbiased way.

It is widely believed that when neutral hydrogen is observed in an elliptical galaxy it is the result of a recent accretion of a gas-rich companion galaxy. Indeed, gas-rich elliptical galaxies are often classified as “peculiar.” This implies that by studying such galaxies one is considering only a subset of the whole population of early-type galaxies, namely those for which it is likely that some interaction and/or accretion has occurred. However, when investigating the evolution of the whole group of early-type galaxies, it could be important not to restrict samples to “pure” elliptical galaxies with no optical peculiarities, since gas-rich systems may represent an important phase in the evolution of many early-type galaxies and give us important information on the formation and evolution of these systems. At high redshift, similar processes will have been more common.

The correlation between optical “peculiarities” and the increased probability of finding H i can be interpreted (van Gorkom & Schiminovich 1997) either as an effect of the evolutionary stage of these galaxies (accretion of H i is a normal phase in the evolution of these galaxies) or as an effect of environment (the fraction of peculiar elliptical galaxies in the Revised Shapley-Ames Catalog goes from 5% in clusters to almost 50% in the field) or (perhaps more likely) as a combination of the two. If the accretion of gas is a normal event in the evolution of many or most early-type galaxies, this raises questions such as how much of the observed ISM is due to small accretion events and to what extent parallels with sp-
eral galaxies exist, whether in major mergers a significant fraction of the gas remains and, if so, how long does the ISM survive, and whether it will settle in a disklike structure.

Recently, there have been several studies of major mergers (i.e., mergers of two disk galaxies) and the fate of gas in these systems (Hibbard & van Gorkom 1996; Hibbard & Mihos 1995). These studies have shown the importance of the late infall of gas, possibly leading to extended, long-lived, gas-rich structures in elliptical galaxies. Indeed, an increasing number of early-type galaxies are known that have a surprisingly large amount of H i distributed in quite regular structures (i.e., disks or rings, e.g., in IC 2006, NGC 4278, NGC 2974, NGC 5266, IC 5063). The regular structure of these disks and rings means that they are relatively old, indicating that some early-type galaxies have a long-lived ISM. In such galaxies, the cold ISM is not a peculiarity, but a fundamental constituent.

Apart from the origin and evolution of the neutral hydrogen in early-type systems, studying H i in these objects and, in particular, in dust lane elliptical galaxies may give accurate estimates of the mass distribution at large radii in these galaxies. Bertola et al. (1993) combined mass-to-light ratio (M/L) values derived from H i data with estimates for the central M/L (based on optical measurements from ionized gas disks) to show evidence for an increasing M/L with radius, supporting the idea of a dark halo around elliptical galaxies. However, estimates of M/L from H i data are only available for a handful of well-studied elliptical galaxies (e.g., IC 2006, Franx, van Gorkom, & de Zeeuw 1994; NGC 1052, van Gorkom et al. 1986; NGC 4278, Raimond et al. 1981 and Lees 1994; and NGC 5266, Morganti et al. 1997).

It is important to increase the number of galaxies for which a similar analysis using H i data can be done. This requires not only finding elliptical galaxies with H i, but finding those in which the H i has settled into a regular disk. For dust lane elliptical galaxies, regular large-scale dust could indicate the presence of a regular disk, and this is particularly valuable if we want to determine the intrinsic shape of the galaxy and the mass-to-light ratio.

In this paper, we present new observations of neutral hydrogen in dust lane elliptical galaxies. The presence of dust lanes is often considered a peculiarity in an elliptical galaxy. Thus, for the reasons mentioned above, dust lane elliptical galaxies are good targets in which to search for neutral hydrogen. Systematic optical searches for dust in elliptical galaxies (Goudfrooij & de Jong 1995; van Dokkum & Franx 1995) have found dust lanes and patches in the inner regions of about 50% of the observed galaxies. Recent HST studies have shown that a large fraction (40%) of elliptical galaxies have dust of some sort visible in optical images (Rest et al. 2001) either in filamentary form, in nuclear disks, or in more large-scale disks. In this paper, we study five galaxies with large-scale dust lanes (Centaurus A–like), mainly taken from the compilation of Sadler & Gerhard (1985): NGC 1947, NGC 3108, ESO 263-G48, NGC 7049, and NGC 7070A. Table 1 summarizes the main properties of these five galaxies. H i observations of these galaxies were made with the Australia Telescope Compact Array (ATCA) as part of a long-term project to increase the number of early-type galaxies with detailed H i images (Morganti et al. 1997, Morganti, Oosterloo, & Tsevtanov 1998; Oosterloo et al. 1999a, 1999b, 2001; Sadler et al. 2000). We present the results from these new observations in § 3, and in § 4 we discuss them in the context of existing H i data on dust lane elliptical galaxies in the literature. In this paper, we use $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$.

2. OBSERVATIONS AND DATA REDUCTION

All five galaxies were first observed with the most compact configuration available with the ATCA (375 m array). The two detected galaxies (NGC 1947 and NGC 3108; see below) were then observed with other ATCA configurations to image the emission in more detail. Table 2 summarizes the H i observations. We used a 16 MHz band with 512
velocity channels centered on the optical velocity of each galaxy. The final velocity resolution (after Hanning smoothing the data) is \( \sim 12 \text{ km s}^{-1} \).

We observed each galaxy for about 12 hr in each run (with the exception of NGC 7070A), with calibrators observed every hour to monitor gain and phase changes. The flux density scale was set by observations of PKS 1934–638, for which we adopted a flux density of 14.9 Jy at 1400 MHz. This source was also used as bandpass calibrator.

The spectral data were calibrated with the MIRIAD package (Sault, Teuben, & Wright 1995), which has several features particularly suited for ATCA data. The continuum subtraction was also done in MIRIAD by using a linear fit through the line-free channels of each visibility record and subtracting this fit from all the frequency channels (i.e., UVLIN; Cornwell, Uson, & Haddad 1992; Sault 1994). An interference spike generated by the ATCA data acquisition system is present at 1408 MHz, but this does not compromise the interpretation of the data.

For the objects that were observed with more than one ATCA configuration, we combined the data from different runs after calibration and continuum subtraction. The final cubes were made with natural, uniform, or robust (or Briggs’) weighting (Briggs 1995). Table 3 lists the corresponding rms noise and size of the restoring beams.

The moment analysis of the data cube was done using GIPSY (Allen, Ekers, & Terlouw 1985). The total intensity of the H\textsc{i} emission was derived from a data cube produced by smoothing spatially the original cube to a resolution about twice lower than the original. This smoothed cube was used as mask for the original cube: pixels with a signal below 3 \( \sigma \) in the smoothed cube were set to zero in the original cube (van Gorkom & Ekers 1989).

H\textsc{i} was not detected in three of the target galaxies, and for these galaxies, the upper limits on H\textsc{i} emission were calculated as three times the statistical error on having no signal over 50 independent velocity elements (corresponding to 600 km s\(^{-1}\)) and over four synthesized beams.

The continuum data were taken from the emission-free channels in the line data. They were also reduced using MIRIAD, and Table 4 summarizes the results. The final continuum images were made with uniform weighting.

### 3. RESULTS

The results of our H\textsc{i} and radio continuum observations are summarized in Table 5. In H\textsc{i}, we detected two of the five galaxies observed, and three of the five were detected as continuum sources. We now give some details of the individual galaxies.

#### 3.1. NGC 1947

NGC 1947 is an E1 galaxy with a system of at least three concentric minor-axis dust lanes (Bertola, Galletta, & Zeilinger 1992). The galaxy also has a ring of CO emission (Sage & Galletta 1993) and ionized gas (Möllenhoff 1982) with the same position angle as the dust lane. The stars in NGC 1947 rotate around the galaxy’s minor axis, perpendicular to the ionized gas rotation axis (Bertola et al. 1992).

The optical spectrum has central emission lines with intensity ratios typical of LINERs (low-ionization nuclear emission-line regions; Heckman 1980), and an H\textsc{x} + [N \textsc{ii}] image (Goudfrooij et al. 1994) shows that the ionized gas has a regular, disklike distribution centered on the galaxy nucleus.

We detect \( 3.4 \times 10^8 M_\odot \) of H\textsc{i} in NGC 1947, very similar to the derived H\textsc{2} mass. The H\textsc{i} emission spans a wide velocity range (from \( \sim 900 \) to \( \sim 1450 \) km s\(^{-1}\)) with a width (at 20\% level) of \( \sim 550 \) km s\(^{-1}\). The corresponding value for \( M_{\text{H}\textsc{i}}/L_B \) is 0.019 \( M_\odot/L_B \odot \). The velocity centroid of the H\textsc{i} is at \( \sim 1180 \) km s\(^{-1}\), close to the optically measured value in Table 1. The neutral hydrogen emission is extended and

### TABLE 2

| Galaxy       | Date       | Configuration | Baseline Range (m) | Frequency (MHz) | Time (hr) |
|--------------|------------|---------------|--------------------|----------------|-----------|
| NGC 1947     | 1996 Sep   | 375           | 31–459             | 1416           | 12        |
|              | 1995 Sep   | 750D          | 31–719             | 1416           | 12        |
|              | 1995 May   | 1.5D          | 107–1439           | 1416           | 12        |
| NGC 3108     | 1996 Apr   | 375           | 31–459             | 1407           | 12        |
|              | 1996 Nov   | 750A          | 77–735             | 1407           | 12        |
| ESO 263-G48  | 1996 Apr   | 375           | 31–459             | 1407           | 12        |
| NGC 7049     | 1997 Sep   | 375           | 31–459             | 1409           | 12        |
| NGC 7070A    | 1996 Sep   | 375           | 31–459             | 1409           | 6         |
|              | 1997 Sep   | 375           | 31–459             | 1409           | 6         |

### TABLE 3

| Parameters                                      | NGC 1947 | NGC 3108 | ESO 263-G48 | NGC 7049 | NGC 7070A |
|------------------------------------------------|----------|----------|-------------|----------|-----------|
| Field center (J2000.0):                         |          |          |             |          |           |
| R.A.                                           | 05 26 47 | 10 02 29 | 10 31 11    | 21 19 00 | 21 31 47  |
| Decl.                                          | –63 45 40| –31 41 01| –46 15 16   | –48 34 19| –42 51 47 |
| Synthesized beam (arcsec)                       | 55 \times 52 | 135 \times 57 | 160 \times 98 | 148 \times 98 | 170 \times 92 |
| Beam P.A. (deg)                                 | 5        | 7        | 1           | –1       | 0.9       |
| rms noise in channel maps (mJy beam\(^{-1}\))  | 0.9      | 0.9      | 1.15        | 1.48     | 0.83      |

### Instrumental Parameters: H\textsc{i} Observations

- Field center (J2000.0):
  - R.A.:
  - Decl.:
  - Synthesized beam (arcsec):
  - Beam P.A. (deg):
  - rms noise in channel maps (mJy beam\(^{-1}\)):
elongated along P.A. ~ 127°, i.e., the same position angle as the dust lane, as can be seen from Figure 1, where contours in total H i are superimposed on a deep optical image kindly provided by D. Malin. Although the H i signal is quite weak (the peak in the cube is only ~5 mJy beam⁻¹), it is clear that the distribution of H i is quite regular. The H i is not only aligned with the dust lane, but rotates in the same sense and with the same amplitude as the CO. The total extent of the H i is ~2' (∼13 kpc) in radius, i.e., ~6.2 times the optical half-light radius R_eff.

Position-velocity plots along the major axis of the H i distribution (Fig. 2a) and along P.A. = 90° (Fig. 2b) confirm that the H i is in a warped rotating disklike structure associated with the dust lane. The velocity increases rapidly in the inner part (less than 300 pc) with a “discontinuity” observed in the center, but the projected velocity appears to decrease in the outer parts. The observed morphology of the dust lanes suggests that the H i might also lie in three or more concentric rings. This may explain the discontinuity seen near the systemic velocity. The combination of a number of rings, together with the fact that the spatial resolution of the H i data is relatively low, can reproduce the distribution of the H i in the position-velocity plot. The morphology of the dust lanes suggests that the whole structure is probably warped, and the decrease in projected velocity at large radii is most likely due to this warp.

The average H i surface density is 0.3 M☉ pc⁻². The distribution peaks in the center, and it is likely that in the center the H i surface density is high enough for star formation to occur. In the radio continuum, we detect a single point source with a flux density of ~13 mJy (at 1416 MHz) coincident with the optical nucleus. This appears to arise from a central region of star formation—the FIR-to-radio ratio q (see Helou, Soifer, & Rowan-Robinson 1985) is 2.25 for NGC 1947, close to the mean values of 2.14 for spiral galaxies (Helou et al. 1985) and 2.55 for low-luminosity elliptical galaxies (Sadler et al. 2000). Thus, the H i and star formation properties of NGC 1947 appear to resemble those of the low-luminosity elliptical galaxies observed by Sadler et al. (2000), consistent with its relatively low optical luminosity (M_B = −20.2 mag).

We also detected H i emission from a companion galaxy, ESO 085-GA088, at a projected separation of 16′ (100 kpc) from NGC 1947. This is an early-type spiral, probably of similar type to the Sombrero galaxy (D. Malin 1998, private communication), although much less luminous (M_B ~ −17.5). Unfortunately, our observations of this galaxy are strongly affected by primary-beam attenuation, especially on the northern side. Nevertheless, our data show (Fig. 3) that this galaxy is quite H i-rich (M_H i/L_B ≥ 0.2), with a very extended H i distribution (R_H i/R_B,25 ≥ 4). The projected rotation velocity of about 85 km s⁻¹ appears constant out to the largest measured point, implying a mass-to-light ratio of M/L_B ~ 20/σ_i at a radius of ~13 kpc.

3.2. NGC 3108

NGC 3108 is an elliptical galaxy with a minor-axis dust lane (see Fig. 4) that has been studied in detail by Caldwell (1984). Figure 5 shows the light profile measured from a V-band image obtained at Cerro Tololo Inter-American Observatory (CTIO), with the surface brightness plotted against the radius R (a straight line would indicate an exponential profile), against log R, and against R/14 (a de Vaucouleurs profile). A de Vaucouleurs profile with an effective radius of R_eff = 25.9 fits the data well, although there is evidence of a very faint disk perpendicular to the major axis of the main body. The surface brightness profile in Figure 5 differs slightly from that published by Caldwell (1984) from photographic data (being systematically fainter by about 0.6 mag), probably because of difficulties in calibrating the older photographic data.

Caldwell (1984) pointed out a misalignment between the main dust lane and the minor axis of the light distribution. Figure 6 shows optical images (taken with the CTIO 4 m PFCCD in 1984 and with the CTIO 0.9 m telescope in 1998) in which a model, based on the light profile, for the light distribution has been subtracted and a second image where the galaxy has been divided by this model.

Two dust lanes can then be seen, along with a possible inner shell. Figure 6b shows some excess luminous material that appears to form a counterpart to the large dust lane (already mentioned in Caldwell 1984). The dust lane that appears (in projection) at larger radii is at position angle ∼109°, while the dust lane projected against the nucleus has a position angle of roughly 130°, which is closer to the position angle of the minor axis of the galaxy (the position angle of the optical major axis is 45°). Caldwell (1984) also detected a disk of ionized gas in the inner 10°.

Our H i observations show that NGC 3108 is a very interesting galaxy. Not only do we detect a large amount of H i (4.6 × 10⁹ M☉, giving a value of M_H i/L_B ~ 0.093), but the neutral hydrogen is quite extended and very regularly distributed and oriented perpendicular to the optical major axis.

---

**Table 4**

**INSTRUMENTAL PARAMETERS: RADIO CONTINUUM OBSERVATIONS**

| Galaxy       | Array        | Beam (arcsec) | P.A. (deg) | rms (mJy beam⁻¹) |
|--------------|--------------|---------------|------------|------------------|
| NGC 1947.....| 375          | 80 × 71       | 8          | 0.40             |
| NGC 3108.....| 750          | 90 × 37       | 13         | 0.45             |
| ESO 263-G48...| 375          | 93 × 68       | 0          | 0.35             |
| NGC 7049.....| 375          | 93 × 68       | −4         | 0.15             |
| NGC 7070A... | 375          | 100 × 92      | 4          | 0.43             |

---

**Table 5**

**PROPERTIES OF THE OBSERVED GALAXIES**

| Properties                  | NGC 1947 | NGC 3108 | ESO 263-G48 | NGC 7049 | NGC 7070A |
|-----------------------------|----------|----------|-------------|----------|-----------|
| M_H i (10⁹ M☉)              | 0.34      | 4.59     | <0.09       | <0.07    | <0.05     |
| M_H i/L_B                    | 0.019     | 0.092    | <0.0008     | <0.001   | <0.003    |
| M_H i/M_dust                 | 222.9     | 1084.5   | <9.6        | <29.1    | <71.6     |
| δ_21 cm (Jy)                | 0.013     | <0.0014  | 0.022       | 0.049    | <0.0013   |
| log (P_21 cm (W Hz⁻¹))      | 20.95     | <20.67   | 21.96       | 22.08    | <20.56    |
axis. Figure 4 shows the total H\textsc{i} intensity map superposed on an optical image. Although the elongated beam shape of the radio observations has “thickened” the apparent H\textsc{i} distribution, it is clear that the H\textsc{i} is distributed in a regular, rotating disklike structure extended ~2\textdegree 5 (~39 kpc, corresponding to ~5.8 \(R_{\text{eff}}\)) on each side. Figure 7 gives the position-velocity map along the main dust lane (P.A. = 109\textdegree).

The neutral hydrogen is distributed over a wide (\(\sim 600 \text{ km s}^{-1}\) at 20% level) velocity range (from \(\sim 2300\) to \(2900 \text{ km s}^{-1}\)), with a systemic heliocentric velocity of \(2610 \pm 5 \text{ km s}^{-1}\). There is a hint in the total H\textsc{i} image that the H\textsc{i} structure is warped toward larger position angle in the outer parts.

The regular structure of the H\textsc{i} emission is clearly shown by the position-velocity map in Figure 7. The lack of fast-rotating H\textsc{i} near the center suggests that the H\textsc{i} distribution has a central hole of roughly 10’ diameter. In the outer parts of the H\textsc{i} distribution, there are hints of a slight increase (of 15–25 km s\(^{-1}\)) in the projected velocity (more clearly on the eastern side).

Assuming that the H\textsc{i} distribution has a central hole of 1’ diameter, the average surface density of the H\textsc{i} is about 0.5–1 \(M_\odot\) pc\(^{-2}\). The position-velocity map does not suggest that there are large gradients in the surface density of the H\textsc{i}. This means that the H\textsc{i} surface density over most of the disk is probably too low for star formation, although some star formation could occur in some isolated regions. The fact that the H\textsc{i} is aligned with the faint optical disk suggests that some star formation may have happened in the past in the H\textsc{i} disk.

We obtained two long-slit spectra of NGC 3108 with the CTIO 4 m telescope in 1984 and SIT-vidicon in order to study the kinematics of the ionized gas in the center of NGC 3108 (Fig. 8). One spectrum is along the position angle of the outer dust lane (P.A. ~ 109\textdegree), and the other perpendicular to the major axis of the light distribution (P.A. ~ 130\textdegree). The wavelength region covered included the H\alpha and [N \textsc{ii}] emission lines. The derived rotation curves show that the small inner disk of ionized gas has very similar kinematics to the larger H\textsc{i} disk and that both the neutral and the ionized gas have similar rotation velocities. It therefore appears that NGC 3108 has a single gas disk that is mostly ionized in the central regions and becomes mainly neutral beyond 30’ radius.

The gas disk is slightly warped. The P.A. of the central dust lane is around 130\textdegree, while the main dust lane and its associated H\textsc{i} disk have a P.A. of about 109\textdegree. The total H\textsc{i} image suggests that the P.A. increases again in the very outer regions. The position-velocity map suggests that the projected rotation velocities rise slightly in the outer part, probably due to warping of the outer H\textsc{i} disk to higher inclination. Assuming that the outermost H\textsc{i} disk is perfectly edge-on and that the rotation curve is perfectly flat, an increase of roughly 20 km s\(^{-1}\) would imply an inclination of about 70\textdegree for the inner H\textsc{i} disk. This is probably just consistent with the inclination of 75\textdegree for the main dust lane as derived by Caldwell (1984). It does suggest that the rotation curve of NGC 3108 along its minor axis stays flat out to at least six effective radii.

The projected rotation velocity is quite constant at roughly 265 km s\(^{-1}\) from a radius of 5’’ to the very outer regions of the H\textsc{i} disk. Even without any detailed modeling, it is clear that the rotation curve in this galaxy along its minor axis is quite different from what is expected from the light distribution (basically an \(R^{1/4}\) law), an indication of a dark matter halo in NGC 3108. With the approximation of
a spherical mass distribution and circular orbits for the gas, we can make a reasonable estimate for the total mass of NGC 3108. Taking a deprojected (for an inclination of 70°) rotation velocity of 290 km s\(^{-1}\) at 170\(00\), we derive a value for the mass-to-light ratio \(M/L_B\) of \(\sim 18 M_\odot/L_\odot\) at \(6R_{\text{eff}}\).

No radio continuum emission was detected from NGC 3108, with a 3 \(\sigma\) upper limit of \(\sim 1.4\) mJy at 1.4 GHz. This implies an upper limit to the star formation rate of \(1 M_\odot\) yr\(^{-1}\).

NGC 3108 is part of a small group of galaxies, and we have detected three of them in H\(\alpha\). Two, the Sbc galaxy IC 2539 and an edge-on spiral ESO 435-G028, have already been detected in H\(\alpha\) by Theureau et al. (1998). The third is a faint, low surface brightness, anonymous galaxy (A1000−31) at \(\alpha = 10^h00^m58^s, \delta = -31^\circ24'12''\) (J2000.0) at a heliocentric velocity of \(\sim 2820\) km s\(^{-1}\) for which we find \(M_{H\alpha} = 6.7 \times 10^8 M_\odot\). A1000−31 also appears to be very hydrogen-rich (see Fig. 9).

### 3.3. ESO 263-G48

This is a major-axis dust lane elliptical galaxy for which the IRAS data suggests an unusually high dust mass: \(M_{\text{dust}} = 9.8 \times 10^6 M_\odot\). Surprisingly, no H\(\alpha\) was detected in association with this galaxy in our ATCA data, and our upper limit is \(M_{H\alpha} < 0.9 \times 10^8 M_\odot\). From this, we derive a tight upper limit to the ratio of the H\(\alpha\) mass to blue luminosity of \(M_{H\alpha}/L_B < 0.0008\). From the upper limit on \(M_{H\alpha}\), we obtain a value of \(M_{H\alpha}/M_{\text{dust}} < 10\). Typical values for this ratio are from a few hundred to over 1000 (Henkel &
so the neutral-to-dust ratio seems to be very low in this galaxy, although a few more galaxies are known with similarly low values for $M_{\text{HI}}/M_{\text{dust}}$. Inspection of the IRAS data shows that perhaps the FIR fluxes are somewhat uncertain because large complexes of FIR cirrus are found right near ESO 263-G48, and confusion could play some role. Still, a clear point source can be seen in the FIR data, and ESO 263-G48 most likely is poor in atomic hydrogen compared with what is expected from the FIR fluxes.

We do detect $\sim 6 \times 10^8 M_\odot$ of H I from a low surface brightness companion galaxy (see Fig. 10), ESO 263-G47, at a projected distance of 120 kpc, with a heliocentric velocity of 2396 ± 15 km s$^{-1}$.

In the radio continuum, we detected a single point source with a 1.4 GHz flux density of $\sim 22$ mJy, coincident with the optical nucleus of ESO 263-G48. Radio continuum measurements of this galaxy have previously been made at $\sim 1''$ resolution with the VLA by Sadler, Jenkins, & Kotanyi (1989), who detected a source 15'' in size, extended along a P.A. of 100° (i.e., nearly perpendicular to the dust lane), and with a flux density of 13.0 mJy at 5 GHz. They also measured a core flux density of 1.5 mJy at 5 GHz within the central 1''. The 1.4 GHz continuum flux density is roughly what would be expected from the radio-FIR correlation (see, e.g., Wunderlich, Wielebinski, & Klein 1987) based on the IRAS flux of ESO 263-G48, but the radio morphology of a linear source centered on the nucleus and extending perpendicular to the dust lane (also seen in an unpublished 1.4 GHz VLA image by Laing & Kotanyi 1996, private communication) is much more suggestive of an active nucleus with jets. The nature of the radio continuum emission from ESO 263-G48 therefore remains unclear.

3.4. NGC 7049

NGC 7049 is an S0 galaxy with a major-axis dust lane and is undetected in H I ($M_{\text{HI}} < 0.7 \times 10^8 M_\odot$), from which we derive $M_{\text{HI}}/L_B < 0.001$. The galaxy is detected by IRAS and, as for ESO 263-G48, we have a low upper limit to the atomic gas–to–dust ratio of $M_{\text{HI}}/M_{\text{dust}} < 29$, which is far lower than the typical value of several hundred to a thousand seen in early-type galaxies.

In the radio continuum, we detect a point source coincident with the nucleus of NGC 7049 with a flux density of $\sim 49$ mJy at 1.4 GHz. The galaxy was also detected as a continuum source by Sadler (1984), who measured flux densities of 75 and 35 mJy with the Parkes telescope at frequencies of 2.7 and 5.0 GHz, respectively. Slee et al. (1994) detected a compact, flat-spectrum radio core with flux density $\sim 15$ mJy at 0''03 resolution with the Parkes-
Tidbinbilla Interferometer at 2.3 GHz, implying that NGC 7049 hosts an active nucleus.

We detect H\textsubscript{i} emission from a companion galaxy in the field of NGC 7049, the spiral galaxy ESO 235-G85, which is about 7' away (90 kpc) and has a heliocentric velocity of 2024 ± 20 km s\textsuperscript{-1} (see Fig. 11).

3.5. NGC 7070A

NGC 7070A is an S0/a galaxy with a skewed dust lane intermediate in orientation between the major and minor axes. It was undetected in our ATCA observations, both in H\textsc{i} and in the radio continuum. We measure an upper limit to the neutral hydrogen mass of $M_{H\textsc{i}} < 0.5 \times 10^{8} M_{\odot}$, giving $M_{H\textsc{i}}/L_B < 0.003$. As with the other two dust lane galaxies undetected in H\textsc{i}, we find a low upper limit for the atomic gas–to–dust ratio: $M_{H\textsc{i}}/M_{\text{dust}} < 72$.

We do detect H\textsc{i} emission from the nearby spiral galaxy NGC 7070. Figure 12 shows the total H\textsc{i} image for this galaxy, and we measure a heliocentric velocity of 2450 ± 20 km s\textsuperscript{-1}.

4. OTHER DETECTIONS OF H\textsc{i} IN DUST LANE GALAXIES

In the literature, we have found four more dust lane elliptical galaxies for which H\textsc{i} imaging data are available. Two of them have been observed by us (NGC 5266, Morganti et al. 1997; and IC 5063, Morganti, Oosterloo, & Tsvetanov 1998; Oosterloo et al. 2000), and the other two are the well-known galaxies NGC 5128 (Centaurus A, van Gorkom et al. 1990; Schiminovich et al. 1994) and NGC 1052 (van Gorkom et al. 1986). We summarize the data for these galaxies in Table 6 and discuss their characteristics briefly here.

NGC 5266 is a minor-axis, dust lane elliptical galaxy with a very large amount of H\textsc{i}, about $2.4 \times 10^{10} M_{\odot}$, giving $M_{H\textsc{i}}/L_B \sim 0.18$. The gas extends to $\sim 8'$ (~140 kpc) in radius. Most of the H\textsc{i} lies almost orthogonal to the optical dust lane (Morganti et al. 1997), and only a small fraction of the H\textsc{i} is associated with the dust lane. The inner half of the H\textsc{i} appears to be in a reasonably regular structure, while the H\textsc{i} more distant from the center is probably not yet settled. A value of $M/L_B \sim 8 M_{\odot}/L_{B,\odot}$ at $\sim 4R_{\text{eff}}$ was found.
IC 5063 (PKS 2048–572) is an early-type galaxy hosting a Seyfert 2 nucleus with a dust lane along the major axis. It also has a high H\textsc{i} content: $8.4 \times 10^9 M_\odot / L_B = 0.13$. The H\textsc{i} emission is elongated ($\sim 38$ kpc each side) in the direction of the dust lane and of the ionized gas disk (Morganti et al. 1998). The H\textsc{i} is distributed in a regularly rotating disk with a slight warp. If we assume circular orbits and a spherical mass distribution, we find $M / L_B$ to be $\sim 14 M_\odot / L_B$ at about 5.4$R_{\text{eff}}$.

In NGC 5128, the neutral hydrogen appears to be largely associated with the dust lane (van Gorkom et al. 1990). In the inner part, the H\textsc{i} velocities match the optical emission-line velocities, while in the outer parts, the gas disk seems to be not yet settled into a stable orbit. Recently, H\textsc{i} emission has also been detected further out in this galaxy, at distances up to 15 kpc from the nucleus (Schiminovich et al. 1994). This outer H\textsc{i} appears to be in a partial ring inclined with respect to the dust lane, rotating in the same sense as the main body of the galaxy.

NGC 1052 is classified as an E3 galaxy with a minor-axis dust lane. H\textsc{i} was first detected by Knapp, Faber, & Gallagher (1978), and its distribution has been studied in detail by van Gorkom et al. (1986). They found the H\textsc{i} distributed over about 3 times the size of the optical galaxy and roughly perpendicular to the major axis (i.e., roughly aligned with the dust lane). The distribution of the H\textsc{i} is not very regular, especially in the outer regions where tidal tails are observed.

NGC 5363 is another early-type galaxy with dust lanes in which H\textsc{i} has been detected (see, e.g., Thuan & Wadiak 1982). However, only single-dish data are available, and little is known about the distribution and kinematics of the H\textsc{i}.

5. DISCUSSION

We have detected and imaged the neutral hydrogen in two of the five dust lane, early-type galaxies observed and are able to put sensitive upper limits on the H\textsc{i} content of the remaining three galaxies. An interesting result is the large amount of H\textsc{i} in one of the objects, NGC 3108. With $4.6 \times 10^9 M_\odot$ of neutral hydrogen, NGC 3108 has a value of $M / L_B = 0.09$, which is at the gas-rich end of the distribution characteristic of elliptical galaxies (Knapp, Turner, & Cunniffe 1985) and is similar to that found in many luminous spiral galaxies. The H\textsc{i} in NGC 3108 is distributed in a very regular disk that is quite large ($\sim 40$ kpc radius) and

![Light profile of NGC 3108 based on a V-band image (from the CTIO 4 m PFCCD). The surface brightnesses is plotted against the radius $R$, against log $R$, and against $R^{1/4}$.

**Fig. 5.**

**TABLE 6**

| Dust Lane Galaxies from the Literature | Galactic  | $D$ (Mpc) | $L_B$ ($10^{10} L_\odot$) | $M_{\text{H}}$ ($10^9 M_\odot$) | log $P_{21\text{cm}}$ (W Hz$^{-1}$) | $T_{\text{dust}}$ (K) | $M_{\text{dust}}$ ($10^2 M_\odot$) | $L_{\text{FIR}}$ ($10^9 L_\odot$) | $M_{\text{H}}$/$M_{\text{dust}}$ | $M_{\text{H}}$/$L_B$ | $M_{\text{H}}$/$M_{\text{dust}}$ |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| IC 5063 .......... | 68.0 | 6.3 | 8.4 | 23.87 | 54 | 12.3 | 30.3 | 6.5 | 0.13 | 6798 |
| NGC 5266....... | 61.5 | 13.9 | 25.2 | 21.74 | 31 | 61.3 | 9.4 | 22.2 | 0.18 | 380 |
| NGC 5128....... | 3.7 | 2.4 | 0.4 | 23.52 | 36 | 7.6 | 10.0 | 2.0 | 0.017 | 285 |
| NGC 1052....... | 29.4 | 3.6 | 0.46 | 22.95 | 41 | 1.9 | 1.2 | 0.33 | 0.013 | 2455 |
appears to be only slightly warped. The H\textsc{i} disk appears to have a central hole that is filled by a disk of diffuse emission from ionized gas. The average H\textsc{i} surface density (0.5–1 \(M_\odot\)/pc\(^2\)) is too low for large-scale star formation.

The other galaxy (NGC 1947) in which H\textsc{i} is detected is less gas-rich with \(M_{H\textsc{i}}/L_B \sim 0.019\), which is a more typical value for those elliptical galaxies that are detected in H\textsc{i}. As in NGC 3108, the H\textsc{i} in NGC 1947 extends to several effec-
tive radii and appears to be a disk that, in contrast to the disk in NGC 3108, is strongly warped.

5.1. ISM Content

The fact that we do not detect the other three galaxies in H I means that there is a large range in ISM properties in dust lane elliptical galaxies, as there is for early-type galaxies in general. This is not only the case for the H I content, but also in the relative content of different indicators of a cold ISM. The upper limits for $M_{\text{H}_2}/M_{\text{dust}}$ for the nondetections are quite strict, considering that typical values for this ratio (and as observed in NGC 1947 and NGC 3108) are between a few hundred to a few thousand, although a few more galaxies with very low values exist (Henkel & Wiklind 1997). It is quite unlikely that $M_{\text{H}_2}/M_{\text{dust}}$ is so low because of most of the H I being ionized, since such large amounts of ionized gas would be detected easily. A possibility would be that much of the gas in these galaxies is in molecular (H$_2$) rather than atomic form. An example of such a galaxy is NGC 759, for which $3.5 \times 10^6 M_\odot$ of dust is detected (Wiklind et al. 1997), while a 5 $\sigma$ upper limit of $10^8 M_\odot$ exists for the amount of H I in this galaxy (Oosterloo, Morganti, & Wiklind 2002). This means that for NGC 759 $M_{\text{H}_2}/M_{\text{dust}} < 30$. However, 2.4 $\times 10^9 M_\odot$ of molecular hydrogen is detected in this galaxy (Wiklind et al. 1997). This means that $M_{\text{gas}}/M_{\text{dust}} \sim 700$, not outside the normal range of values for this ratio (Henkel & Wiklind 1997). It also means that all the cold gas in NGC 759 is in molecular form. The molecular hydrogen is found to be very centrally concentrated in NGC 759 (Wiklind et al. 1997). Perhaps in NGC 759 the atomic gas, which is normally more extended than the molecular gas, has been removed by interactions with neighboring galaxies, leaving NGC 759 poor in H I but not poor in molecular gas. NGC 759 is indeed in a denser environment than that of galaxies like NGC 3108 or NGC 5266.

Little data on the molecular gas content of these galaxies are available, although the work of Lees et al. (1991) suggests that the molecular gas mass is typically similar to the H I mass, but a large scatter also exists here. As noted in Table 1, NGC 1947 has been detected in CO (Sage & Galllletta 1993) with an implied H$_2$ mass of $3.9 \times 10^8 M_\odot$, which is slightly higher than our measured H I mass. Clearly, we need more sensitive CO observations of these galaxies to clarify the state of their ISM. The 158 $\mu$m line of [C II] detected by the Infrared Space Observatory (see, e.g., Malhotra et al. 1999) has the potential to provide an independent and very sensitive probe of the cool ISM in early-type galaxies, but only a few observations are available so far.

---

Fig. 7.—Position-velocity map of NGC 3108 obtained from a slice along P.A. = 109°. The contour levels are from −2.7 to 13.5 mJy beam$^{-1}$ (excluding the zero contour) in steps of 1.35 mJy beam$^{-1}$.

Fig. 8.—Radial velocities with respect to the systemic velocities of the central ionized gas disk, as derived from the optical spectra. The arrows indicate the projected velocities of the H I at larger radii.
5.2. Origin of the H\textsc{i} Disks/Rings

It is generally assumed that the neutral hydrogen in elliptical galaxies is related to a recent merger or accretion event. In most numerical simulations of merging galaxies of similar size, most of the gas quickly falls toward the center, where it fuels a burst of star formation. The large, regular H\textsc{i} structures seen in some of the galaxies discussed here (in particular, the very regular disk in NGC 3108), the fact that in some galaxies these disks exist from the very center out to radii of several tens of kiloparsecs, and the large amount of H\textsc{i} present in a few galaxies may seem incompatible with this. Perhaps the H\textsc{i} disks are not formed in a merger of similarly sized galaxies, but instead are the result of several smaller accretions that, since such accretions are less “violent,” can lead to the formation of a large regular disk in a way that is, to some extent, similar to how disks in spiral galaxies form. The difference would then be that the surface density in the gas disks in the early-type galaxies is too low for a significant optical disk to form. In a way, they could be “diskless disk galaxies,” or perhaps parallels exist with low surface brightness spiral galaxies. An alternative is that for a relatively uncommon set of initial conditions of a major merger, a large fraction of the gas forms a large gas disk.

One of the main arguments found in the literature for a merger-related origin is that the amount of H\textsc{i} is uncorrelated with the optical luminosity of the galaxy, in contrast to the situation for spiral galaxies (see, e.g., Knapp et al. 1985; Roberts & Haynes 1994). In the dust lane elliptical galaxies discussed here, there is indeed a large scatter in relative H\textsc{i} content, ranging from H\textsc{i}–rich objects such as NGC 5266 (with $M_{\text{H\textsc{i}}}/L_B = 0.18$) to very H\textsc{i}–poor galaxies such as ESO 263-G48 ($M_{\text{H\textsc{i}}}/L_B < 0.0008$) and NGC 7049 ($M_{\text{H\textsc{i}}}/L_B < 0.001$). There also seems to be a large range in the conditions of the ISM, considering the large range in relative amounts of different constituents of the cold ISM.

Optical data suggest that in several of the galaxies discussed here a significant accretion event must have taken place and that the disk is not a result of a slower buildup. NGC 5266 has a very low surface brightness, extended and irregularly shaped optical counterpart to the large-scale H\textsc{i} disk that only shows up at large radius after special data-processing techniques (see Fig. 5 in Morganti et al. 1997). In IC 5063, a deep image (Danziger, Goss, & Wellington 1981) shows a similar faint, irregular, large-scale optical structure with some indications of optical shells. In NGC 5128, optical shells are seen at large radius, and an association of these shells with the H\textsc{i} at large radius has been suggested.
The morphology of these very faint optical counterparts to the outer H\textsc{i} disks indicates that they are structures that are not settled yet and may have formed from stellar material from the progenitors that also provided the H\textsc{i}.

Numerical studies show that a large fraction of the tidal tails formed during the interaction and merger will remain bound to the remnant (Barnes & Hernquist 1996 and references therein). This gas will slowly "fall back" to the main body of the galaxy over a long period of time. For the galaxy NGC 7252, Hibbard & Mihos (1995) predict that about $10^9 M_\odot$ of H\textsc{i} will return within 15–45 kpc in about 3 Gyr, if the gas structures at large radius are not disrupted by companions in the mean time. Some of this gas may not fall into the center. Instead, it may form an extended, low surface density disk. In a crowded environment, this inflow can be disrupted and a disk will not form. The regular kinematics of most of the H\textsc{i}, but with the tail-like features at large radius in NGC 5266, would suggest that this galaxy represents an intermediately evolved result of such a major merger. IC 5063, with a more regular H\textsc{i} distribution, could represent an even older merger remnant. The orbital timescale in the outer parts of the H\textsc{i} disk in NGC 3108 is about $10^9$ yr.

Given that it takes several revolutions for a gas disk to settle, the very regular appearance of this disk, from the center out to $r = 40$ kpc, would mean that, if the disk in NGC 3108 is also due to a single event, it must be an even older merger remnant than IC 5063. The outer isophotes of NGC 3108 are quite boxy, indicating a merger of some size has taken place.

Given the rarity of merger remnants with such a large, regular H\textsc{i} disk, the conditions that gave rise to such a remnant do not occur very often. Nevertheless, it appears that the formation of large gas disks is a rare but natural result of the way early-type galaxies form.

In NGC 1947, no extended low surface brightness structure is seen in the optical (D. Malin 1998, private communication). The amount of gas in NGC 1947 and its lower $M_{H\textsc{i}}/L_B$ may indicate that the H\textsc{i} in this galaxy could result from a single "small" accretion, i.e., an accretion with a mass ratio of more than a few.

5.3. Evolution of the H\textsc{i} Disks

The surface densities of the H\textsc{i} in most of the galaxies are quite low. For NGC 3108, we find that it must be in the...
range \(0.5-1 \, M_\odot \, \text{pc}^{-2}\) over most of the disk. For NGC 1947, we find that the average surface density is \(0.3 \, M_\odot \, \text{pc}^{-2}\), but the value for the central region is probably higher. These surface densities are quite low, and except for the central regions, no large-scale star formation will occur in these galaxies. Not much evolution will happen in these disks at large radii. Even though the galaxies discussed here are early-type galaxies, some of these galaxies will remain gas-rich for a very long period of time, and the gas should be considered a fundamental constituent of the galaxy.

It is worth remarking on the difference between the morphology of the neutral hydrogen in luminous dust lane elliptical galaxies, such as NGC 3108 and NGC 5266, and in low-luminosity E/S0 galaxies. In the low-luminosity galaxies, regular disks of \(\text{H}_\text{i}\), extending out to a few effective radii, are very common (Lake, Schommer, & van Gorkom 1987; Sadler et al. 2000). However, the \(\text{H}_\text{i}\) distribution is strongly peaked toward the center, in contrast to what we see in the more luminous dust lane elliptical galaxies, and the central \(\text{H}_\text{i}\) surface densities in these low-luminosity galaxies are high enough for significant star formation to occur in their centers. Several of the luminous dust lane elliptical galaxies considered here have ionized gas in the central region in the form of disks or rings that, in some cases such as NGC 3108, are inner extensions of the neutral gas disks. The optical spectra of these central ionized gas disks (with the exception of IC 5063, which is a Seyfert 2 galaxy) are typically LINER-like and not typical of star-forming regions. The ionization mechanism of gas in LINERs is still unclear (Colina & Koratkar 1997) but is usually attributed either to shocks (Heckman 1980; Dopita & Sutherland 1995), to old UV-bright, post–asymptotic giant branch stars (Binette et al. 1994), to hot, high-metallicity, O-type stars (Filippenko & Terlevich 1992), or to thermal interaction with a hot ISM (see, e.g., Goudfrooij 1999). Whatever the mechanism, it appears that the conditions in luminous early-type galaxies, in contrast to less luminous, early-type galaxies, are such that the hydrogen near the center cannot remain neutral but becomes ionized.

### 5.4. Dark Matter

Some of the regular \(\text{H}_\text{i}\) structures can be used for studying the dark matter properties at large radii. In general, a
complication is that it is often difficult to determine the inclination of the \( \text{H}_\text{i} \) disk in early-type galaxies (see, e.g., Sadler et al. 2000). For dust lane galaxies, however, the situation is more promising, since the inclination of the \( \text{H}_\text{i} \) structures can be assumed to be close to edge-on, and small uncertainties in the inclination angle do not have a large effect on the derived total mass. In NGC 3108, the rotation curve is basically flat, as it is in luminous spiral galaxies. If we assume circular orbits and a spherical mass distribution, we derive a value of \( M/L_B \sim 18 \ M_\odot/L_{B,\odot} \) at 6 \( R_{\text{eff}} \) for NGC 3108. This compares well with values of 15–20 \( M_\odot/L_{B,\odot} \), which are typically found in elliptical galaxies at radii of 6–7 \( R_{\text{eff}} \) using \( \text{H}_\text{i} \) data (see, e.g., Morganti et al. 1997, 1998). These numbers imply that significant amounts of dark matter are present at large radii in these galaxies.

It is interesting to compare the mass-to-light ratio values derived from neutral hydrogen data with those obtained from X-ray observations, since very different tracers of the potential are used. From X-ray data, values of \( M/L_V \sim 25h_{100} \ M_\odot/L_{V,\odot} \) within 6 \( R_{\text{eff}} \) are usually found (see, e.g., Loewenstein 1999), which converts to \( M/L_B \sim 16 \ M_\odot/L_{B,\odot} \) for the value of the Hubble constant used by us in this paper. Although both methods have their uncertainties, there appears to be good agreement between the \( \text{H}_\text{i} \) and X-ray estimates of the masses of early-type galaxies.

6. CONCLUSIONS

We have presented new \( \text{H}_\text{i} \) observations of five dust lane elliptical galaxies. In two galaxies, we detect \( \text{H}_\text{i} \) emission. In both galaxies, the \( \text{H}_\text{i} \) is in a warped, disklike structure, with (in particular, in NGC 3108) regular kinematics. For the remaining three galaxies, we derive sensitive upper limits that imply a very low \( \text{H}_\text{i} \) content compared to the dust mass. Differences in merging history may perhaps explain the large range in the relative content of different tracers of the cold ISM.

By adding data from the literature, we find several dust lane elliptical galaxies, for which the \( \text{H}_\text{i} \) is regularly distributed in disks or rings of several tens of kiloparsecs in size, and at least three dust lane galaxies with more than \( 10^9 \ M_\odot \) of \( \text{H}_\text{i} \). The data collected suggest that most dust lane galaxies probably represent the results of major mergers as seen at a late stage in their evolution. In these systems, the late infall of gas has produced regular, settled \( \text{H}_\text{i} \) disks. In some cases, the disk could also be the result of accretions of several small galaxies, spread out in time. The \( \text{H}_\text{i} \) surface density is quite low over most of these disks, and little or no recent star formation has occurred (except possibly in the very center). These gas disks will evolve very slowly, and the galaxies will remain gas-rich for a very long period of time. The presence...
of large, regular H\textsc{i} structures suggests that a significant fraction of elliptical galaxies may have a long-lived cool ISM.

The regular distribution and kinematics of the H\textsc{i} in NGC 3108 allow us to derive the mass-to-light ratio in this galaxy. We find a value of $M/L_B \sim 18 M_\odot/L_B$. This value is very similar to what is found in other elliptical galaxies based on H\textsc{i} data. Estimates of $M/L$ using H\textsc{i} are very similar to those based on X-ray data.

We would like to thank M. M. Phillips and R. Covarrubias for taking the 0.9 m image of NGC 3108 and David Malin for kindly providing the deep optical image of NGC 1947.

REFERENCES

Allen, R. J., Ekers, R. D., & Terlouw, J. P. 1985, Proc. Intern. Workshop on Data Analysis in Astronomy, ed. L. Scarsi & V. di Gesu (London: Plenum), 271

Barnes, J. E., & Hernquist, L. E. 1996, ApJ, 471, 115

Bertola, F., Galletta, G., & Zeilinger, W. W. 1992, A&A, 254, 89

Bertola, F., Pizzella, A., Persic, M., & Salucci, P. 1993, ApJ, 416, L45

Binette, L., Magris, G., Stasinska, G., & Bruzual, G. 1994, A&A, 292, 13

Briggs, D. 1995, Ph.D. thesis, New Mexico Inst. Mining Tech.

Caldwell, N. 1984, ApJ, 278, 96

Colina, L., & Koratkar, A. 1997, in ASP Conf. Ser. 113, Emission Lines in Active Galaxies: New Methods and Techniques, ed. B. M. Peterson, F.-Z. Cheng, & A. S. Wilson (San Francisco: ASP), 477

Cornwell, T. J., Uson, J. M., & Haddad, N. 1992, A&A, 258, 583

Danziger, J. I., Goss, W. M., & Wellington, K. J. 1981, MNRAS, 196, 845

Davies, R. L., & Illingworth, G. D. 1986, ApJ, 302, 234

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Jr., Buta, R. J., Paturel, G., & Fouqu\'e, P. 1991, Third Reference Catalogue of Bright Galaxies (New York: Springer)

Dopita, M., & Sutherland, R. 1995, ApJ, 455, 468

Filippenko, A., & Terlevich, R. 1992, ApJ, 397, L79

Franx, M., van Gorkom, J. H., & de Zeeuw, T. 1994, ApJ, 436, 642

Goudfrooij, P. 1999, in ASP Conf. Ser. 163, Star Formation in Early-Type Galaxies, ed. P. Carral & J. Cepa (San Francisco: ASP), 55

Goudfrooij, P., & de Jong, T. 1995, A&A, 298, 784

Goudfrooij, P., de Jong, T., Hansen, L., & Norgaard-Nielsen, H. U. 1994, MNRAS, 271, 833

Heckman, T. 1980, A&A, 87, 152

Hibbard, J. E., & van Gorkom, J. H. 1996, AJ, 111, 655

Kauffman, G. 1996, MNRAS, 281, 487

Knapp, G. R. 1999, in ASP Conf. Ser. 163, Star Formation in Early-Type Galaxies, ed. P. Carral & J. Cepa (San Francisco: ASP), 119

Knapp, G. R., Faber, S. M., & Gallagher, J. S. 1978, AJ, 83, 139

Knapp, G. R., Turner, E. L., & Cunniffe, P. E. 1985, AJ, 90, 454

Knapp, G. R., Guhathakurta, P., Kim, D.-W., Jura, M. A. 1989, ApJS, 70, 329

Lake, G., Schommer, R. A., & van Gorkom, J. H. 1987, ApJ, 314, 57

Lees, J. F. 1994, in Mass-Transfer Induced Activity in Galaxies, ed. I. Shlosman (Cambridge: Cambridge Univ. Press), 432

Lees, J. F., Knapp, G. R., Rupen, M. P., & Phillips, T. G. 1991, ApJ, 379, 177

Loewenstein, M. 1999, in ASP Conf. Ser. 163, Star Formation in Early-Type Galaxies, ed. P. Carral & J. Cepa (San Francisco: ASP), 153

Malhotra, S., et al. 1999, in The Universe as Seen by ISO, ed. P. Cox & M. F. Kessler (ESA-SP-427) (Noordwijk, ESA), 813

Mollenhoff, C. 1982, A&A, 108, 130

Morganti, R., Oosterloo, T., & Tsvetanov, Z. 1998, AJ, 115, 915

Morganti, R., Sadler, M. E., Oosterloo, T. A., Pizzella, A., & Bertola, F. 1997, AJ, 113, 937

Oosterloo, T., Morganti, R., & Sadler, E. M. 1999a, in ASP Conf. Ser. 163, Star Formation in Early-Type Galaxies, ed. P. Carral & J. Cepa (San Francisco: ASP), 72

———. 1999b, Publ. Astron. Soc. Australia, 16, 28

———. 2001, in ASP Conf. Ser. 240, Gas and Galaxy Evolution, ed. J. Hibbard, M. Rupen, & J. van Gorkom (San Francisco: ASP), 251

Oosterloo, T. A., Morganti, R., Tzioumis, A., Reynolds, J., King, E., McCulloch, P., & Tsvetanov, Z. 2000, AJ, 119, 2085

Oosterloo, T. A., Morganti, R., & Wiklind, T. 2002, in preparation

Plana, H., & Boulesteix, J. 1996, A&A, 307, 391

Raimond, E., Faber, S. M., Gallagher, J. S., III, & Knapp, G. R. 1981, ApJ, 246, 708

Rest, A., van den Bosch, F. C., Jaffe, W., Tran, H., Tsvetanov, Z., Ford, H. C., Davies, J., & Schafer, J. 2001, AJ, 121, 2431

Roberts, M. S., & Haynes, M. P. 1994, ARA&A, 32, 115

Sadler, E. M. 1984, AJ, 89, 53

Sadler, E. M., & Gerhard, O. E. 1985, MNRAS, 214, 177

Sadler, E. M., Jenkins, C. R., & Kotanyi, C. G. 1989, MNRAS, 240, 591

Sadler, E. M., Oosterloo, T., Morganti, R., & Karakas, A. 2000, AJ, 119, 1180

Sage, L., & Galletta, G. 1993, ApJ, 419, 544

Sault, R. J. 1994, A&AS, 107, 55

Sault, R. J., Teuben, P. J., & Wright, M. C. H. 1995, in ASP Conf. Ser. 77, Astronomical Data Analysis Software and Systems IV, ed. R. Shaw, H. E. Payne, & J. J. E. Hayes (San Francisco: ASP), 433

Schiminovich, D., van Gorkom, J. H., van der Hulst, J. M., & Kasow, S. 1994, ApJ, 423, L101

Slecer, B. E., Sadler, M. E., Reynolds, J. E., & Ekers, R. D. 1994, MNRAS, 269, 928

Theureau, G., Bottinelli, L., Coudreau-Durand, N., Gouguenheim, L., Hallet, N., Loulergue, M., Paturel, G., & Teerikorpi, P. 1998, A&AS, 130, 333

Thuan, T. X., & Wadiak, E. J. 1982, ApJ, 252, 125

van Dokkum, P. G., & Franx, M. 1995, AJ, 110, 2027

van Gorkom, J. H., & Ekers, R. D. 1989, in ASP Conf. Ser. 6, Synthesis Imaging in Radio Astronomy, ed. R. A. Perley, F. R. Schwab, & A. H. Bridle (San Francisco: ASP), 341

van Gorkom, J. H., Knapp, G. R., Raimond, E., Faber, S. M., & Gallagher, J. S. 1986, AJ, 91, 791

van Gorkom, J. H., & Schiminovic, D. 1997, in ASP Conf. Ser. 116, The Nature of Elliptical Galaxies, ed. M. Arnaboldi, G. S. Da Costa, & P. Saha (San Francisco: ASP), 310

van Gorkom, J. H., van der Hulst, J. M., Haschick, A. D., & Tubbs, A. D. 1990, AJ, 99, 1781

Wunderlich, E., Combes, F., Henkel, C., & Wyrowski, F. 1997, A&A, 323, 727

Wunderlich, E., Wielebinski, R., & Klein, U. 1987, A&AS, 69, 487