THE FINE STRUCTURE AND OUTSKIRTS OF DDO 154

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ABSTRACT

Mapping of the H I disk of the isolated irregular galaxy DDO 154 with the C array of the Very Large Array (VLA) and with the 3/2 upgraded Arecibo beam is presented. Our results show a truncation (or temporary drop) of the H I disk at a column density around $10^{19}$ atoms cm$^{-2}$, consistent with theoretical expectations for the truncation produced by the extragalactic UV field. We also detect a marginally significant levelling off of the H I distribution along the continuation of the major axis at a column density near $2 \times 10^{18}$ atoms cm$^{-2}$. The VLA results show that the gas beyond $\sim 6'$ in radius must be relatively smooth, with no structure larger in size than $\sim 300$ pc exhibiting a density contrast of a factor of 10 or more. However, there is considerable structure on a few hundred parsec scale in the gas disk at smaller radii, even well outside the regions where there are visible stars. Two prominent cavities well removed from any significant stellar populations are studied. While the energies required for evacuation are consistent with those produced by multiple supernovae, there is no visible trace of stars within a kiloparsec of the center of the larger cavity, and the smaller of the two cavities is centered just outside the 26.5 mag arcsec$^{-2}$ B isophote. The velocity dispersion of the gas, measured within our 270 pc beam, is 7–8 km s$^{-1}$ throughout the disk (to 6' radius). This translates to a scale height of $\sim 700$ pc at the point where the rotation curve flattens at a radius of $\sim 4.5$ kpc. Velocity profiles are well fitted by single Gaussians at all points.

Key words: galaxies: individual (DDO 154) — galaxies: irregular — intergalactic medium — radio emission lines

1. INTRODUCTION

The nearby irregular galaxy DDO 154 has received a great deal of attention for its extraordinarily extended H I disk (Krumm & Burstein 1984; Hoffman et al. 1993; Carignan & Purton 1998) and its global dynamics, which seem to be dominated by dark matter at all radii (Carignan & Freeman 1988; Carignan & Beaulieu 1989) but require some physics beyond that of the Navarro, Frenk, & White (1996, 1997) “universal” halo (Burkert & Silk 1997; Gelato & Sommer-Larsen 1999; Ghigna et al. 2000; Milgrom & Braun 1988). Since the H I disk extends so far beyond the visible stars while the galaxy is apparently isolated from all neighbors, in contrast to most other examples of H I envelopes that extend far outside their optical components, DDO 154 would seem to be an excellent case in which to study the structure and thermodynamic state of a relatively pristine gas cloud. There are two major questions: (1) How does the neutral gas disk terminate—is it truncated abruptly by the extragalactic UV radiation field (Corbelli & Salpeter 1993; Maloney 1993; Dove & Shull 1994), by UV photons leaking out from the central stellar disk (Bland-Hawthorn, Freeman, & Quinn 1997), or by some other process? (2) What is the fine structure and velocity dispersion of the outer gas disk—is that gas, presumably well removed from energy input from star formation and supernovae, smoothly distributed or as filamentary as the inner parts of the Magellanic Clouds (Stanimirović et al. 1999; Kim et al. 1998) or well-resolved spiral galaxies (Braun 1997)?

To broach question 1, we extended our Arecibo map of the outskirts of the galaxy, taking full advantage of the enhanced sensitivity and greatly reduced sidelobes of the upgraded telescope. For question 2, we undertook to improve, by a factor of 3, the angular resolution of the mapping of the H I envelope to assess the fine structure of the gas disk and in the hopes of finding sufficient column density to perform emission/absorption studies against one or more of the NRAO VLA Sky Survey (NVSS) continuum sources in the outskirts of the southwestern quadrant of the H I disk. The average column density from the D array, Dominion Radio Astrophysical Observatory (DRAO), and Arecibo mapping cited above would be too low; however, if the outer envelope proved to be filamentary, there would be a reasonable probability that such studies would be feasible.

In § 2, our Arecibo study of the outskirts of the southernmost quadrant of the galaxy is presented. We detail our VLA C array map of the galaxy in § 3. Section 4 is a discussion of the various theoretical points of interest, and a summary and our conclusions follow in § 5.

2. ARECIBO OBSERVATIONS

Our mapping of the outskirts of the southern quadrant of DDO 154 was conducted as a commissioning phase project...
at the upgraded Arecibo Observatory\textsuperscript{2} in 1998 July and August. We used the Gregorian feed system with the "L narrow" receiver in total power (position-switched) mode, with 6.10 kHz (about 1.3 km s\textsuperscript{-1}) channel spacing. Calibration was accomplished by observing several continuum sources from the VLA calibrator list, chosen to have small size compared with the 3:2 beam. In addition, we reobserved several spiral galaxies for which we had high signal-to-noise preupgrade H\textsc{i} measurements and which were known to be \(\lesssim 3:2\) in extent.

At the time of these observations, final focusing of the Gregorian feed system was still underway, and the first sidelobe ring at 21 cm was less uniform than in the final configuration and varied significantly with azimuth and zenith angle. For a fuller characterization of the first sidelobe ring

\textsuperscript{2} The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under cooperative agreement with the National Science Foundation.
of the current instrument, see Heiles et al. (2001). By scanning the beam across strong point sources at close to DDO 154’s declination as they drifted across the field of view, we were able to determine that we could keep the center of the galaxy in the weakest part of the sidelobe ring (15 dB or more down from the peak of the beam) as long as the point being observed lay between the center of the galaxy and the center of the dish at that moment. Consequently, we planned our observations day by day to make sure that we kept that orientation, starting with points on the southeastern side of the galaxy as it entered the field of view and working around the rim to points on the southwestern side as the galaxy left the field of view.

The sidelobe contributions are not negligible, however, even though they are greatly reduced from those of the preupgrade circular feed. The beam had a null ring (at least 20 dB down) about 9′ × 7.5′ in diameter, and the first sidelobe peaked in a ring about 11.6′ × 10.6′ in diameter with a maximum that varied from about −16 dB to about −13 dB; as discussed above, only the weaker part of the ring extended toward the center of the galaxy in our observations. A −15 dB uniform ring would have a total effective
area 25%–30% of the main beam, so that one sextant of the ring would give about 4% of the response of the main beam. To correct for those sidelobe contributions, we interpolated between the points on our preupgrade flat-feed map of the inner portions of the galaxy (Hoffman et al. 1993) to estimate the flux that would fall in each sextant of the sidelobe ring, and then we subtracted 4% of that flux from the spectrum obtained at the position of the main beam. The spectrum obtained at each observed position and the estimated sidelobe contribution to that spectrum are displayed in Figure 1. The positions in relation to those mapped with the preupgrade flat feed in Hoffman et al. (1993) are shown in Figure 2.

There is an additional worry: scattering from the triangular platform and support cables is expected to produce far sidelobes of uncertain magnitude (but considerably less than the first sidelobe ring) that vary greatly with azimuth and zenith angle. That expectation is consistent with our observation that the ability of the first sidelobe ring to account for the observed flux varies erratically from point to point, at least away from the extension of the major axis. Far sidelobes seem to be a more reasonable explanation for that patchy low-level H I, since the emission not accounted for by the first sidelobe has a velocity width comparable with that of spectra from points near the galaxy’s center, not as narrow as the outer VLA C array spectra shown in the following section. For the far sidelobes to account for the residual flux we see, the magnitude of the response for the portion of the far sidelobe that catches the center of the galaxy would have to be about $-25 \text{ dB}$ for a wide range of distances from the center of the beam. Nevertheless, in those cases where the remnant flux falls within the velocity bounds of the profiles obtained near the center of the galaxy, we conservatively attribute that flux entirely to incompletely removed sidelobes. The only points with marginally significant emission that we cannot so attribute to sidelobes are those at the end of the warped major axis, labeled “J” and “K”, since that flux is seen at velocities higher than any from the central parts of the galaxy. Taking, conservatively, the uncertainty in the corrected flux to be $\frac{1}{2} \times 2 \times (50 \text{ km s}^{-1}) \times (\text{rms flux})$ added in quadrature to the uncertainty in the sidelobe contribution (approximately the square root of the number of contributing points times 20% of the sidelobe flux), the sidelobe-corrected emission we detect at points J and K is marginally significant at levels of 2 $\sigma$ and 3 $\sigma$, respectively. In Figure 3, we show the sum of those two spectra. Calculating uncertainties as above, the summed signal is significant at just over 3 $\sigma$.

From the measured fluxes, after subtraction of the first sidelobe contributions, H I column densities can be calculated. The profiles obtained for points in this quadrant of the galaxy are approximately 50 km s$^{-1}$ broad, so in those cases where the sidelobe subtraction has left less than $2 \times (50 \text{ km s}^{-1}) \times (\text{rms flux})$, we take that expression to be
the effective upper limit on the corrected flux. The fluxes and column densities, both as measured and corrected, are given in Table 1.

The (warped) major axis of the galaxy follows points 1–4, J, and K through the south-western quadrant. A second radial spoke, for comparison, can be taken to include points “y,” “z,” “E,” and “F.” The galaxy’s center is at the point of convergence of the two spokes, marked by a filled circle. The run of column density (corrected for first sidelobe contamination) versus radius along those two spokes is shown in Figure 4. For the major axis, the center and points 1–4 are from our preupgrade flat-feed data, as reported in

| Label | Radius (arcmin) | P.A. (deg) | R.A. (B1950) | Decl. (B1950) | Raw Flux (mJy km s$^{-1}$) | rms (mJy) | Corr. Flux (mJy km s$^{-1}$) | Raw $N_{H_1}$ ($10^{17}$ cm$^{-2}$) | Corr. $N_{H_1}$ ($10^{17}$ cm$^{-2}$) |
|-------|----------------|------------|--------------|---------------|-----------------------------|---------|-----------------------------|---------------------------------|-----------------------------------|
| A     | 10.4           | 123        | 12 52 18.7   | 27 19 48      | 229                         | 0.61    | <61                         | 64                              | <17                               |
| B     | 13.5           | 133        | 12 52 23.8   | 27 16 04      | 122                         | 0.65    | <106                        | 34                              | <29                               |
| C     | 10.3           | 144        | 12 52 06.7   | 27 16 57      | 244                         | 0.72    | <72                         | 68                              | <20                               |
| D     | 14.0           | 149        | 12 52 11.8   | 27 13 13      | 136                         | 0.58    | <112                        | 38                              | <31                               |
| E     | 11.7           | 163        | 12 51 54.7   | 27 14 03      | 232                         | 0.75    | <75                         | 65                              | <21                               |
| F     | 15.6           | 163        | 12 51 59.8   | 27 10 22      | 101                         | 0.46    | <84                         | 28                              | <23                               |
| G     | 17.9           | 174        | 12 51 47.9   | 27 07 31      | 89                          | 0.50    | <82                         | 25                              | <23                               |
| H     | 14.1           | 177        | 12 51 42.7   | 27 11 12      | 227                         | 0.77    | <120                        | 63                              | <33                               |
| I     | 17.1           | 187        | 12 51 30.7   | 27 08 21      | 62                          | 0.40    | <40                         | 17                              | <11                               |
| J     | 17.0           | 200        | 12 51 13.6   | 27 09 17      | 140                         | 0.67    | 71                          | 39                              | 20                                |
| K     | 20.6           | 204        | 12 51 01.7   | 27 06 26      | 85                          | 0.68    | 72                          | 23                              | 20                                |
| L     | 17.9           | 212        | 12 50 56.4   | 27 10 10      | 60                          | 0.45    | <45                         | 17                              | <13                               |
| M     | 15.6           | 223        | 12 50 51.3   | 27 13 54      | 142                         | 0.54    | <54                         | 39                              | <15                               |
| N     | 14.1           | 237        | 12 50 46.3   | 27 17 31      | 123                         | 0.80    | <80                         | 34                              | <22                               |

**NOTE.**—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
Hoffman et al. (1993). Uncertainties in these points are of the order of 10%. The outer two points are from our new data (J and K) for the southwestern end of the major axis. For these, in each radius, we display two points connected by a vertical bar. The top point in each case assumes no sidelobe contribution, while the bottom point has been corrected for a uniform $-15$ dB sidelobe ring. Spectrum J corresponds to the pair of filled squares at radius 17.0, spectrum K to the outermost pair of filled squares. There are likely to be far sidelobe contributions to the off-major-axis positions (crosses) as discussed in the text, so we interpret the bottom points at those positions to be upper limits as well, indicated by the downward arrows. For the inner points (center, I–3, and the two preupgrade points on the second spoke), uncertainties in column density are of the order of 10%.

![Graph](image)

**Fig. 4.**—Column density as a function of radius along the major axis, following the warp (from the galaxy’s center and points 1–4, J, and K in Fig. 2; filled squares) and along a second spoke (from points “y,” “z,” “E,” and “F” in Fig. 2; crosses). The newly acquired beam positions (postupgrade) have two points connected by a vertical bar; the top point in each case assumes no sidelobe contribution, while the bottom point has been corrected for a uniform $-15$ dB sidelobe ring. Spectrum J corresponds to the pair of filled squares at radius 17.0, spectrum K to the outermost pair of filled squares. There are likely to be far sidelobe contributions to the off-major-axis positions (crosses) as discussed in the text, so we interpret the bottom points at those positions to be upper limits as well, indicated by the downward arrows. For the inner points (center, I–3, and the two preupgrade points on the second spoke), uncertainties in column density are of the order of 10%.

### TABLE 2

| Parameters | Values |
|------------|--------|
| Date       | 1998 Dec 24 |
| Pointing Center R.A. (B1950) | 12 51 30.0 |
| Pointing Center Decl. (B1950) | 27 20 00 |
| Heliocentric velocity (km s$^{-1}$) | 375 |
| Array       | C |
| Channels    | 128 |
| Channel separation (km s$^{-1}$) | 2.6 |
| Time on-source (minutes) | 609 |
| Beam (arcsec) | $18 \times 13$ |
| Noise rms per channel (mJy beam$^{-1}$) | 0.76 |

3 The Very Large Array of the National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement with Associated Universities, Inc.
12\textsuperscript{h}51\textsuperscript{m}44\textsuperscript{s}, +27\textdegree24'50" (B1950). In Figure 6, each channel map is shown with a single contour indicating the outermost extent of the optical images from the Digitized Sky Survey (DSS). The more easterly cavity lies on the very edge of the optical image, just beyond the 26.5 mag arcsec\textsuperscript{–2} B isophote, as shown in Carignan & Beaulieu (1989). In the DSS image, there is a faint smudge that might be an H\textsc{ii} region near the center of the cavity. The more westerly cavity, however, has no indication of any starlight whatsoever within it. Neither can any H\textsc{ii} emission be found associated with either cavity in the image acquired by Hunter, Elmegreen, & Baker (1998), reproduced in Figure 7, nor in the deeper H\textsc{ii} image of Kennicutt & Skillman (2001).

The diameters of the cavities are about 40" and 60", respectively, or about 600 and 900 pc for our assumed 3.2 Mpc distance to DDO 154. The velocity depths are about 20.6 and 33.6 km s\textsuperscript{–1} (corresponding to expansion velocities of order 10.3 and 16.8 km s\textsuperscript{–1}). However, as shown in Figures 8 and 9, the spectra in the interiors of the cavities do not give clear indications of expanding walls at the front and rear; rather, the gas in the interior seems to partake of the same velocity field as the gas immediately adjacent to the cavity—the neutral component in each cavity is simply less dense. There are no indications of vorticity, although in the major axis–velocity map (Fig. 10) there is a dense ridge at the inner edge of the western cavity that clearly departs from uniform circular motion.

The velocity field contours from fitting Gaussians to our C array mapping are shown in Figure 5. A position-velocity map, along the major axis and summed over the minor axis, is shown in Figure 10. The more easterly and more westerly holes fall at about 0" and –80", respectively, on the position axis, and there is a dense ridge of material that deviates from circular motion just inside the westerly hole. The rotation curve derived from the velocity field is shown in Figure 11. It does not differ significantly in the inner parts from the lower resolution mapping of Carignan & Freeman (1988) or Carignan & Purton (1998), so evidently beam smearing (Swaters, Madore, & Terwhella 2000; van den Bosch et al. 2000) has not significantly affected the discussions of mass.
Fig. 6.—Gray-scale images of neutral hydrogen emission in each velocity channel with an outer contour from a smoothed optical image from the DSS superposed. The contour corresponds approximately to 26 mag arcsec$^{-2}$. The gray scale is in units of mJy beam$^{-1}$. 
Fig. 6.—Continued
modeling cited above. Further analysis and discussion of the rotation curve will be deferred to a forthcoming paper (Swaters et al. 2001).

The enhanced resolution in angle and velocity of our observations do allow us to determine the velocity dispersion of the gas. Selected velocity profiles are displayed in Figure 12; each is fitted well by a single Gaussian, with no significant residuals. A map of FWHM of Gaussians fit to profiles at each pixel is presented in Figure 13. The corresponding dispersions are 7–8 km s$^{-1}$ over most of the outer parts of the galaxy, rising to about 9 km s$^{-1}$ in the central part (more or less coincident with the part that has formed stars). The rising portion of the rotation curve would increase the velocity dispersion in the central regions (out to radius 50$^\circ$) of the galaxy by somewhat less than 2 km s$^{-1}$, about what is observed, so it is not clear whether any part of the increase in the dispersion in the center can be attributed to heating by stars. What is clear is that the dispersion in the outer parts, well outside the stellar portion, is still characteristic of the warm neutral medium (gas temperature of order $10^4$ K) rather than anything much colder.

The scale height of the gas in the outer parts of the disk can be estimated following Puche et al. (1992). We adopt 7.5 km s$^{-1}$ as a typical velocity dispersion at radii 4′′–6′′. The volume mass density in the disk at that radius is essentially all due to dark matter (Carignan & Purton 1998), which we take to be distributed spherically for convenience. Then the mass density at radius $r$ is just

$$
\rho(r) = \frac{1}{4\pi G r^2} \frac{d}{dr} \left[ v(r)^2 r \right],
$$

where $v(r)$ is the circular velocity at radius $r$. Where the rotation curve is flat, this reduces to

$$
\rho(r) = \frac{v(r)^2}{4\pi G r^2}. (2)
$$

In the case of DDO 154, the rotation curve goes flat at a radius of ~4.5 kpc (Carignan & Purton 1998), then declines gradually. Taking the circular velocity to be 47 km s$^{-1}$ at that point, we find a volume density of $\rho = 1.37 \times 10^{-25}$ g cm$^{-3}$ = 0.002 $M_\odot$ pc$^{-3}$ at that radius. The scale height is

$$
h = \frac{\sigma}{[4\pi G \rho]^{1/2}} (3)
$$

(Kellman 1972; van der Kruit 1981), giving $h = 718$ pc for DDO 154 at a radius of 4.5 kpc (4′′), well outside the stellar disk.

4. DISCUSSION

4.1. Outer Envelope

The most reasonable interpretation of the Arecibo results presented in § 2 is that the H I phase truncates rather abruptly, falling by nearly an order of magnitude in less than 3.5 (3.2 kpc) at a column density around $10^{19}$ atoms cm$^{-2}$, with at best marginal indications of emission an order of magnitude lower continuing along the major axis. As discussed in § 2, the uncertainty in the column density at point J is of the order of a factor of 2, and the outermost point (K) should perhaps be regarded as an upper limit only. While the suggested upturn in the rotation curve at
Fig. 7.—Neutral hydrogen contours from the total H I map compared with a gray-scale representation of the Hα emission. In the top panel, only the 250 mJy km s$^{-1}$ beam$^{-1}$ contour is shown to outline the two prominent cavities. In the bottom panel, only higher contours (400, 500, and 600 mJy km s$^{-1}$ beam$^{-1}$) are shown to highlight the relationship between the Hα and H I peaks. The prominent Hα-emitting cloud just west of the larger H I cavity appears to be associated with a foreground star.
Fig. 8.—Velocity profiles across the more westerly cavity. A spectrum is plotted for every second pixel.

Fig. 9.—Same as for Fig. 8, but for the more easterly cavity
large radii is intriguing, the data in hand do not warrant much further discussion of the marginally significant continuation of the major axis. Still more Arecibo mapping, as well as a detailed study of the sidelobes of the upgraded Arecibo beam, is indicated.

That the neutral phase should abruptly decrease at such a column density is no surprise, since similar truncation has been observed in M33 (Corbelli, Schneider, & Salpeter 1989; van Gorkom 1993). A theoretical explanation, in terms of photoionization by extragalactic UV, has been offered by Corbelli & Salpeter (1993), Maloney (1993), and Dove & Shull (1994). However, detection of Hα flux around NGC 253 by Bland-Hawthorn et al. (1997) is claimed by those authors to require a more local photoionizing source, e.g., UV leaking out of the disk of the galaxy. DDO 154, forming stars much more quiescently, is unlikely to be leaking enough Hα to produce the truncation we claim to see so far outside the star-forming region. A definitive test would be to compare the truncation along the line of nodes of the warped H I disk with the direction perpendicular to that, since UV would be expected to escape mainly perpendicular to the disk of the galaxy and so could truncate the disk where a warp has lifted the edge of the disk out of the central plane but not along the line of nodes (Bland-Hawthorn et al. 1997). Since we see, if anything, more abrupt truncation along the off–major axis spoke, which should be closer to the line of nodes, the data presented here suggest that the photoionizing flux is extragalactic in this case.

From our Arecibo data (Hoffman et al. 1993 and § 2) and the VLA plus DRAO map of Carignan & Purton (1998), we know that H I remains above a few times $10^{19}$ atoms cm$^{-2}$ for another 6′ or 8′ beyond that detected in the data of § 3. The outer gas must therefore be rather smooth, without structure that would amount to density contrasts of more than a factor of 2 or 3 on the scale of our 18′ beam, since our C array detection threshold is a bit less than $10^{20}$ atoms cm$^{-2}$ on that scale and much emission at a few times $10^{19}$ atoms cm$^{-2}$ is evidently resolved out. Structure such as we see in the inner 6′, with density contrasts of a factor of 10 on 18′ scales, does not continue into the outer envelope. On the surface, this argues for the structure ultimately to be generated by stellar processes. However, we argue in the following subsection that the connection between stars and H I structure cannot be too intimate.

### 4.2. Cavity Generating Mechanisms

The cavities described in § 3.1 are fairly typical of the holes found in Holmberg II (Puche et al. 1992), IC 2574
F.1. Rotation curves for the galaxy as a whole (circles) and for the receding (upward pointing triangles) and approaching (downward pointing triangles) sides of DDO 154, determined by fitting the velocity field within consecutive annuli. (b) Inclinations (left) and position angles (right) of successive annuli for the galaxy as a whole (circles) and for the receding (upward pointing triangles) and approaching (downward pointing triangles) sides of DDO 154, determined as for (a).

Fig. 11a

Fig. 11b

(Walter & Brinks 1999), and DDO 47 (Walter & Brinks 2001), among others. A similar cavity can be seen in the channel maps for NGC 2366 (Hunter, Elmegreen, & van Woerden 2001). The required energies are consistent with those provided by multiple supernovae in a star formation region. However, at least one of these cavities is well outside the region where any star formation has taken place. Nothing is visible in the interior of the western cavity in B, R, or Hα images. Similar claims have been made for many of the H I holes in Holmberg II (Rhode et al. 1999), although those holes do not appear to be as far removed from the stellar regions of that galaxy. Imaging in the UV might be more definitive (Stewart & Walter 2000), but to our knowledge no UV image with sufficient resolution has been published. There is considerable resemblance to the giant H I hole in NGC 6822 (de Blok & Walter 2000), although DDO 154 gives no indication of tidal interaction such as that claimed for NGC 6822.

Another hole-making mechanism that has been discussed (Santillán et al. 1999, and references therein) is a collision with a high-velocity cloud (HVC). We cannot rule that out in this case, although we otherwise have no evidence of there being HVC around DDO 154 and would not expect high impact velocities, since the galaxy has low mass. A third mechanism has been proposed recently by Crossthwaite, Turner, & Ho (2000) and supported by numerical hydrodynamical simulations (Wada, Spaans, & Kim 2000): cavities formed as gravitational instabilities in the process of spiral arm formation. While there are no clear indications of spiral arms in either the optical or H I images of DDO 154, a gravitational instability of this sort may still be the best explanation of these cavities. That would require, however, that the bulk of the mass of the galaxy be in the disk, distributed spatially as the H I is distributed. Other researchers have found that the best fit to the VLA plus DRAO rotation curve has dark matter in a slightly flattened (b/a = 0.6) halo (Carignan & Purton 1998) or in a disk as flat as the H I disk (Hoekstra, van Albada, & Sancisi 2001), in each case with density proportional to that of the H I. Modified Newtonian dynamics has been claimed to give a good fit to the rotation curve (Milgrom & Braun 1988) with no dark matter at all.

5. CONCLUSIONS AND SUMMARY

To study physical processes in the outermost H I of a galaxy that is relatively undisturbed by tidal influences, we have pursued complementary mapping of DDO 154 with the Gregorian feed system at the Arecibo Observatory and
Fig. 12.—Velocity profiles at selected points across DDO 154

Fig. 13.—Gray-scale representation of the velocity dispersion (FWHM of fitted Gaussians) map of DDO 154. The gray scale indicates FWHM in km s\(^{-1}\), ranging from 0 to 40 km s\(^{-1}\). There may be some augmentation of the velocity dispersion by the gradient in the rotation curve in the central 50° of the galaxy, but the outer parts of the velocity dispersion field should not be significantly affected by such gradients.
with the C array of the VLA. The 3′2 Arecibo beam gives us the most sensitive available information about the outermost edges of the H I disk, and the C array mapping gives us information about the fine structure of the gas at somewhat smaller radii, but still well outside the stellar disk.

Despite uncertainty about the contribution of far sidelobes to our Arecibo spectra, we interpret our results to show a truncation of the H I disk of DDO 154 at a column density around 10^{19} atoms cm^{-2}, consistent with the truncations observed around the spirals M33 (Corbelli et al. 1989) and NGC 3198 (van Gorkom 1993). This is consistent with theoretical expectations (Corbelli & Salpeter 1993; Maloney 1993; Dove & Shull 1994) for the truncation produced by the extragalactic UV field. There are tantalizing hints that the column density along the continuation of the major axis might level off near 2 × 10^{18} atoms cm^{-2} and at higher velocity than is seen in any other spectrum for the galaxy, but with only marginal significance. A detailed study of the sidelobes of the Gregorian feed system at Arecibo and further mapping of DDO 154 with the Arecibo beam will be required to verify these results.

The VLA results show that the gas beyond ~6′ in radius must be relatively smooth on scales of a few hundred parsecs or larger, with no structure at those scales exhibiting a density contrast of a factor of 10 or more. We do not find sufficient column density against any background continuum sources to warrant absorption studies. However, there is considerable structure in the gas disk at smaller radii, even well outside the regions where there are visible stars. Two prominent cavities well removed from any significant stellar populations were noted, with a pronounced overdensity between them. While the energies required for evacuation are consistent with those produced by multiple supernovae, there is no visible trace of the stars that could have engendered those supernovae within a kiloparsec of the center of the larger cavity. The smaller of the two cavities is centered just outside the 26.5 mag arcsec^{-2} B isophote. Other hole-making mechanisms were discussed in § 4.2, but none presents itself as the obvious choice.

The velocity dispersion of the gas, measured within our 18″ (270 pc) beam, is 7–8 km s^{-1} throughout the disk (to 6′ radius), with a slight enhancement at the galaxy’s center (which could be produced either by increased turbulence associated with star formation or by the rising part of the rotation curve) and a slight diminishment in the center of the larger cavity. Velocity profiles are well fitted by single Gaussians at all points. This translates to a disk scale height of 718 pc at the radius where the rotation curve turns flat, about 4.5 kpc. Detailed discussion of the rotation curve will follow in a separate paper (Swaters et al. 2001).

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