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THE NEUTRAL HYDROGEN CONTENT, STELLAR ROTATION CURVE, AND MASS-TO-LIGHT RATIO OF NGC 4594, THE "SOMBRERO" GALAXY

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ABSTRACT

We have detected 21 cm emission from the "Sombrero" galaxy, NGC 4594. For an assumed distance of 18.6 Mpc, the hydrogen mass is $8.7 \pm 2.6 \times 10^8 M_\odot$, and the ratio $M_{\rm H\,I}/L_{\rm pg}$ is 0.0069 ± 0.0021 in solar units. The gas is probably distributed in a ring and exhibits a classic, double-peaked line profile typical of later-type disk galaxies.

Based on the rotational motions in the gas, corroborated by velocities measured from the stellar absorption lines, we have estimated the mass and mass-to-light ratio. The total mass within a radius of 3′ (16.2 kpc) is $4.3 \pm 0.4 \times 10^{11} M_\odot$, and an upper limit to M/L_B for the spheroidal component is 3–4.

This low value indicates that M/L does not significantly increase away from the nucleus out to a distance of 3′. Since the bulge of NGC 4594 resembles an ordinary elliptical galaxy in many respects, this result may have significant implications for the behavior of M/L in the outer regions of elliptical galaxies as well. It suggests that large increases in M/L for ellipticals, if they occur at all, must take place far out in the halos, where the surface brightness is very low and where the effect will be extremely difficult to measure directly.

A very rough estimate for the amount of H I expected on the basis of the dust content is $2.2 \times 10^9 M_\odot$, a factor of 2.5 greater than the observed value. If this additional hydrogen were in molecular form and associated with dense clouds emitting CO, the predicted CO signal would be below our recently determined upper limit of 0.1 K.

Subject headings: galaxies: individual — galaxies: internal motions — galaxies: stellar content — radio sources: 21 cm radiation

I. INTRODUCTION

The masses and mass-to-light ratios of elliptical galaxies are important to our understanding of the dynamics of regular galaxy clusters, since ellipticals constitute a large fraction of galaxies in such clusters. A direct measurement of the mass-to-light ratio (M/L) for an elliptical galaxy can be easily made only at the nucleus, where the surface brightness is sufficiently great. This restriction to the nucleus is undesirable, however, because the value of M/L for the nuclear region may not be representative of the object as a whole. Moreover, the measurement of M/L based on the nuclear velocity dispersion is somewhat model-dependent and is also subject to observational errors in both the velocity dispersion and the nuclear surface photometry. For all these reasons, it would be desirable to determine M/L far from the nucleus by using some other technique, such as rotational motions. For normal ellipticals, however, this is not usually possible.

The "Sombrero" galaxy, NGC 4594, type Sa, is a potentially important object in this regard because it possesses a large spheroidal component very similar to a normal elliptical in terms of luminosity profile, color, and nuclear velocity dispersion (van Houten 1961; Williams 1976). It also has a fairly prominent disk visible out to large radii, in which the stars are presumably traveling in nearly circular orbits. A measurement of the stellar rotational velocity at the edge of the disk therefore provides an estimate of the circular velocity far out in the halo. The presence of detectable 21 cm emission in this object allows one to determine rotational motions in the gas as well. Finally, the object is seen nearly edge-on, so that corrections for inclination are negligible. For all these reasons, NGC 4594 provides a reasonably clean estimate of the mass-to-light ratio for an elliptical-like population at distances far from the nucleus. We have carried out such measurements for this galaxy and find that M/L_B for the spheroidal component does not exceed 3–4.

II. 21 cm OBSERVATIONS

A first series of 21 cm observations was made in 1976 March with the National Radio Astronomy Observatory[1] 43 m equatorial telescope, whose beam-width is 21′. The dual-polarization receiver, having a system temperature of ~ 50 K, was used with the 384-channel autocorrelator operated in the parallel mode. Data were acquired and reduced following the procedure described by Gallagher, Faber, and Balick (1975, hereafter Paper I). Data were averaged and smoothed first with a Hanning filter (weights of 0.25, 0.50, 0.25) and then a three-channel boxcar (weights of 0.33, 0.33, 0.33). The effective velocity resolution is 33 km s^{-1}. A linear baseline was removed.

The resultant profile, representing a total of 6.4 hours of integration on- and off-source, is shown in Figure 1. The galaxy exhibits a classic, double-peaked line profile with a total width at half-power of 750 km s^{-1}. This large line width accounts for our failure to recognize the signal in our previous observations (Paper I). With the benefit of hindsight, the presence of H I can be discerned in our previously published line profile, but it is confused with the instrumental baseline curvature, and the signal-to-noise ratio is somewhat smaller.

The integrated intensity of the line, $\int T_A dv$, is 3.15 ± 0.95 km s^{-1} K, where the error estimate is $\sigma \Delta v$; σ is the rms scatter of the points about the linear baseline after smoothing, and Δv the total line width of 790 km s^{-1}. The radial velocity of the galaxy is 1090 km s^{-1}, or 930 km s^{-1} with respect to the Local Group (see § III). This value, together with a Hubble constant of 50 km s^{-1} Mpc^{-1}, leads to a distance of 18.6 Mpc. For the 43 m telescope, $M_{\rm H\,I} = 0.80 D^2 \times \int T_A dv \times 10^6\, M_\odot$. This yields $8.7 \pm 2.6 \times 10\, M_\odot$, which is exactly the upper limit stated in Paper I.

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

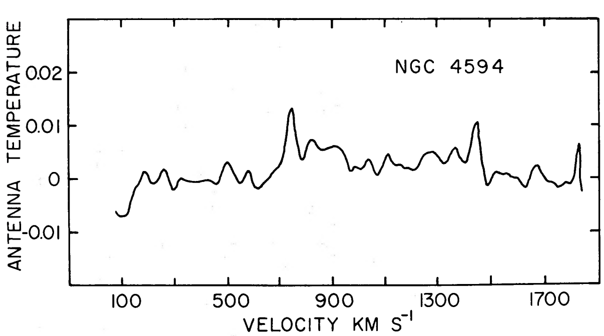

FIG. 1.—The line profile shown is based on the observations taken with the 43 m telescope. The velocity scale is heliocentric. The low-velocity peak occurs at 739 km s^{-1}, and the high-velocity peak at 1448 km s^{-1}.

This mass determination might be somewhat too small, owing to self-absorption by the hydrogen. If the gas is distributed in a uniform disk of radius 3′ (see § III), the optical depth is a few tenths, based on an assumed line-of-sight velocity width of 30 km s^{-1} and a spin temperature of 100 K. Because a realistic estimate of the effect requires detailed information on the distribution and motions of the gas, no correction has been made.

Holmberg's (1958) photographic magnitude for NGC 4594 is 9.18. Using this value, together with an absorption correction A_B of 0.21 mag (corresponding to 0.13 mag absorption at the galactic pole), we obtain a ratio of $M_{\rm H\,I}/L_{\rm pg}$ of 0.0069 ± 0.0021 in solar units. Since the mean value of $M_{\rm H\,I}/L_{\rm pg}$ for Sa galaxies is 0.05–0.10 (Roberts 1969; Balkowski *et al.* 1972), $M_{\rm H\,I}/L_{\rm pg}$ in NGC 4594 is much lower than average and is in fact smaller than the existing upper limits for most elliptical galaxies (e.g., Paper I; Shostak, Roberts, and Peterson 1975; Huchtmeier, Tammann, and Wendker 1975).

Two further observations of NGC 4594 were obtained in 1976 May with the NRAO 91 m transit telescope (half-power beamwidth [HPBW] = 10′) and the same amplifier and receiver, again in parallel mode. These two observations, each representing approximately 8 minutes of integration time on-source, are shown in Figure 2. A linear baseline has been removed, but the data have not been smoothed. The effective resolution is 11 km s^{-1} per channel.

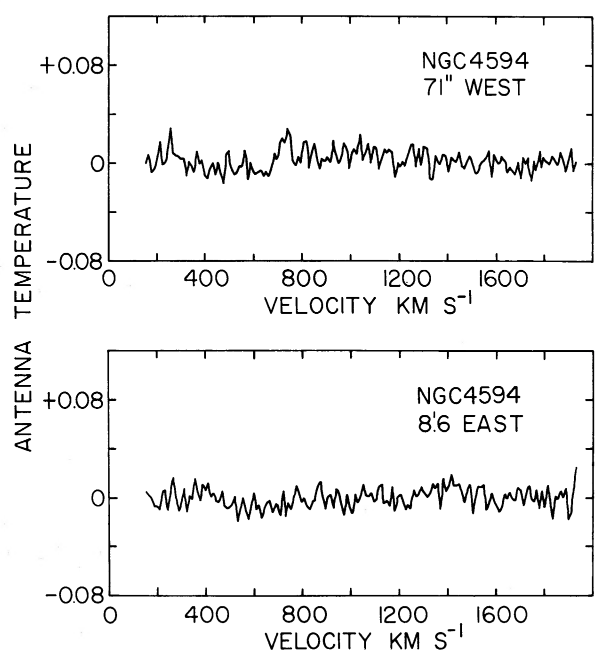

FIG. 2.—Line profiles obtained with the 91 m telescope (beamwidth = 10′). *Top*, telescope centered 71″ due west of nucleus. Low-velocity bump at 730 km s^{-1} is due to approaching H I on western side of galaxy. *Bottom*, telescope centered 8.′6 due east of nucleus. No signal is visible.

The upper profile was observed at the nominal position for the galaxy listed in the *Reference Catalog of Bright Galaxies* (de Vaucouleurs and de Vaucouleurs 1964). According to Gallouet, Heidmann, and Dampierre (1974), this position is in reality 71″ west of the nucleus. The second profile was taken one beamwidth, or 10′, east of the first. No signal is visible on the second profile, but a small bump appears on the first at a velocity of 730 km s^{-1}, corresponding to the low-velocity peak on the profile in Figure 1. The absence of the high-velocity peak is probably due to the fact that the telescope was pointed slightly off the nucleus toward the western side of the galaxy, which is the side approaching us (see § III). The three profiles taken together seem to suggest that the H I is located in a ring between ~2′–5′ in radius. The gas apparently does not extend inward close to the nucleus; otherwise, the high-velocity peak would have been visible in the first 91 m observation. Based on photometry of the dark band, van Houten (1961) found that the dust layer likewise does not extend to the nucleus. This fact, together with an outer radius for the dust layer of 3′ as estimated from direct photographs, suggests that the dust and gas have overlapping radial distributions.

In addition to the H I observations described above, we have also used the 36 foot (11 m) telescope of the NRAO on Kitt Peak to search for CO in the disk of NGC 4594. The observations were taken in 1976 April. A cooled mixer receiver (system temperature ~1500 K) and 256 × 1 MHz filters (velocity width 700 km s^{-1}) were used in four observing sessions under conditions of cool, dry, stable weather. The 1′ beam was directed toward several regions in the disk, all of which nearly filled the beam. The center frequency of the system was tuned to the expected velocity centroid at each position by assuming the velocity pattern for the disk described below. No CO was detected at any location after approximately 3 hours of integration per point. The upper limit to the CO temperature is 0.1 K (3 σ) in each case.

III. STELLAR ROTATION CURVE

In order to compare the velocities of the stars and gas, we have measured the stellar rotation curve of NGC 4594, using the image-dissector scanner attached to the 3 m telescope of the Lick Observatory. Because only two points in the galaxy could be measured at one time, our coverage is limited to discrete points distributed almost exclusively along the western major axis. The observations were taken with the 600 line mm^{-1} grating used in first order, which yields a dispersion on the first cathode of the intensifier chain of 130 Å mm^{-1}. Entrance aperture sizes used are indicated in Table 1. The observations were taken by switching alternately between NGC 4594 and a sky position off the galaxy at intervals of 4 to 8 minutes.

To ensure adequate wavelength accuracy, scans of a Ne–Ar–Hg–He comparison source were taken frequently during the observations. The wavelength stability of the instrument was continuously monitored, using an on-line computer program to determine the channel numbers of the night-sky lines. Updated comparison lamp scans were taken whenever the night-sky drift amounted to 0.25 Å. After the appropriate lamp scans were averaged, a wavelength dispersion curve was calculated for each separate observation on the galaxy by fitting the relationship between wavelength and channel number with a fifth-order polynomial. The rms residuals after this fit averaged 0.3 Å.

TABLE 1

STELLAR RADIAL VELOCITIES*

Position	Velocity (km s^{-1})	No. of Lines	Entrance Aperture†
35″ E‡	1376 ± 20	8‡	2″ × 4″
17″ E	1211 ± 20	5	2″ × 8″
Nucleus‡	1089 ± 15	15‡	2″ × 4″
17″ W	934 ± 20	6	2″ × 8″
25″ W	901 ± 20	9	2″ × 16″
60″ W	835 ± 20	8	2″ × 16″
85″ W	801 ± 20	9	2″ × 16″
120″ W	777 ± 20	6	2″ × 16″
130″ W	788 ± 30	5	3″ × 16″
165″ W	802 ± 30	4	3″ × 16″

* Heliocentric.

† First dimension parallel to major axis; second dimension perpendicular to it.

‡ Based on two separate observations.

As an additional check on the wavelength scale, the sky scans corresponding to each observed point on the galaxy were reduced in a fashion identical to the corresponding galaxy data. Based on the measured wavelengths of the night-sky lines, small corrections were made to the final velocities in order to bring all the wavelength scales into agreement. These corrections were less than or equal to 15 km s^{-1} in all cases.

The radial velocity of each point in the galaxy was measured by cross-correlating sections of the spectrum with a standard scan of the nucleus of M31, observed and reduced in identical fashion. The details of this procedure will be described more fully in a forthcoming paper (Faber and Dressler 1977). The individual velocities from each separate line are shown in Figure 3, and the mean values for each point are shown in Figure 4. The mean heliocentric velocities and their errors are given in Table 1.

A rotation curve for NGC 4594 was published earlier by Pease (1916) based on a spectrum taken with the 0.9 m Crossley telescope of the Lick Observatory. The agreement with the present measures is not good. He found a linear rotation curve out to 130″ having a slope of 2.8 km s^{-1} $arcsec^{-1}$, considerably shallower than our slope of 7.6 km s^{-1} $arcsec^{-1}$ near the nucleus. Furthermore, his systemic velocity is 90 km s^{-1} greater than ours. The source of these discrepancies is not known but may perhaps be attributed to the much more primitive equipment at his disposal.[2]

[2] His exposure lasted 80 hours extending over a three-month period.

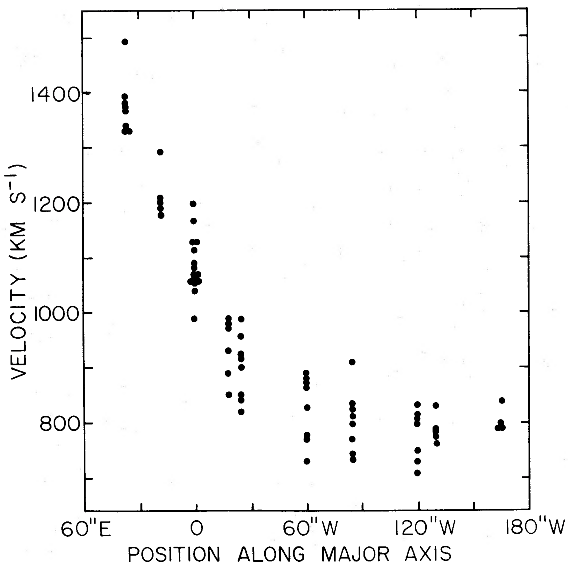

FIG. 3.—Velocities determined from individual stellar absorption lines along the major axis of NGC 4594. From the scatter, the rms error per observation of a single line is found to be 55 km s^{-1}.

If we assume the 21 cm velocity of the galaxy to be the average of the two velocity peaks in Figure 1, we obtain 1093 ± 10 km s^{-1} for the radio line. This value agrees well with the absorption-line velocity of the nucleus, which is 1089 ± 15 km s^{-1}. However, there appears to be a small systematic difference between the stellar rotational velocities and the gas velocity in the outer part of the galaxy. Nowhere do the stars appear to be rotating as rapidly as the gas;

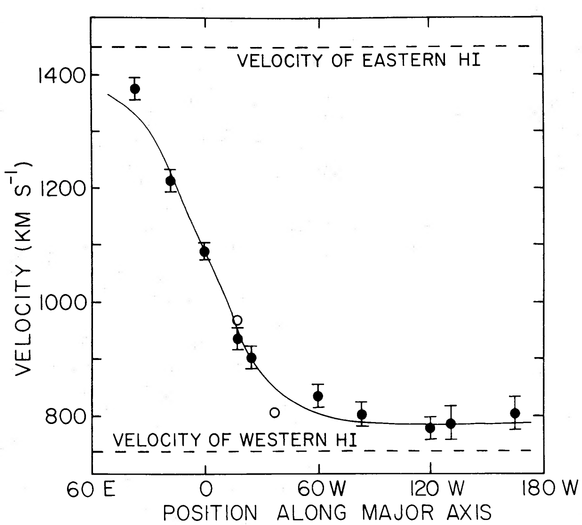

FIG. 4.—Velocities from stellar absorption lines averaged for each point on the galaxy. Solid curve is drawn freehand. *Open circles*, velocities for two points on eastern major axis reflected about nucleus under the assumption that velocities are symmetric about the minor axis. *Dashed lines*, high- and low-velocity peaks from 21 cm profile.

the difference amounts to 50 ± 25 km s^{-1}. Such a difference could be caused by a failure to center the entrance aperture of the spectrograph directly along the major axis. An error of 7″ however, would be required to reduce the rotational velocity by 50 km s^{-1}, whereas we estimate our setting accuracy to be no worse than 3″.

A more likely source of the effect is contamination of the disk light by light of the stars in the spheroidal component, which is not rotating as rapidly. Van Houten's photometry indicates that between 25% and 50% of the light from 30″ to 165″ along the major axis is in fact emitted by the halo (the lower value is valid if the optical depth in the disk is high, obscuring the halo stars behind the disk). This degree of contamination could easily account for the smaller rotational velocity seen in the stars.

IV. MASS AND MASS-TO-LIGHT RATIO

Because of the contamination of the disk light by the bulge component discussed above, the rotation curve of the stars shown in Figure 4 does not reflect the true mass distribution of the system. For this reason we have not constructed a mass model for the system by fitting a polynomial to the rotation curve. Instead, we assume that the gas velocity determined in § II represents the circular velocity at the edge of the dusty disk (radius = 3′) and then estimate the mass and mass-to-light ratio interior to this radius.

Using van Houten's photometry of the disk and bulge, we have integrated the light in the disk and bulge components separately (see Table 2). We have transformed van Houten's yellow magnitudes to the B system by assuming $(B - V) = 1.00$. The bulge magnitude refers to the luminosity within the isophote which intersects the major axis at 3′. It represents the true luminosity of the bulge which would be seen if the disk were not present.[3]

The apparent surface brightness of the disk is undoubtedly strongly affected by the presence of the absorbing layer. However, it is impossible to correct for this effect without a detailed knowledge of the amount and optical properties of the dust. To determine the total disk luminosity, we have therefore simply used van Houten's disk surface-brightness profile uncorrected for absorption. As a result, our disk luminosity, and hence the total luminosity (disk plus bulge), are underestimated by some unknown amount.

To compute the mass, we assume that the matter exterior to the 3′-isophote is distributed in concentric spheroids and hence can be neglected. Then

$$M(R) = \left(\frac{v_c^2 R}{G}\right) \cdot f[\epsilon, \rho(r)] \,, \qquad (1)$$

[3] We have overestimated this luminosity slightly because we have not corrected the surface photometry for the contributions of foreground and background regions of the halo projected along the line of sight. This error is difficult to estimate precisely but is less than 5%.

TABLE 2

MASS AND MASS-TO-LIGHT RATIOS*

	m_B (1)	L ($10^{11} L_{\odot}$) (2)	Mass, H I Velocity ($M_{\odot}$) (3)	Mass, Stellar Velocity ($M_{\odot}$) (4)	M/L_B (H I velocity) ($M_{\odot}/L_{\odot}$) (5)	M/L_B (stellar velocity) ($M_{\odot}/L_{\odot}$) (6)
Bulge within 3′†.....	9.52	1.01	...	...	$< 4.2 \pm 0.4$	$< 3.1 \pm 0.4$
Disk within 3′‡.....	11.93	0.11	...	...	...	...
Total within 3′§.....	9.41	1.12	$4.3 \pm 0.4 \times 10^{11}$	$3.1 \pm 0.4 \times 10^{11}$	3.8 ± 0.3	2.8 ± 0.4

* Assumed distance = 18.6 Mpc; $M_B(\odot) = 5.47$ mag; $A_B = 0.21$ mag.

† Within 3′ isophote.

‡ Uncorrected for effect of absorbing layer.

§ Sum of bulge plus disk.

where $M(R)$ is the mass interior to the spheroid passing through R, v_c is the circular velocity at R, G is the gravitational constant, and f is a correction factor for flattening which is a function of the ellipticity ϵ and the density distribution $\rho(r)$ interior to R. To estimate f we have assumed that the mass distribution is given by a King (1966, 1971) model which has a core radius of 4″ or 360 pc, a value typical of large elliptical galaxies (King 1974). The ellipticity is 0.8, based on van Houten's photometry of the bulge. These assumptions, together with Schmidt's (1965, p. 515) formula (8), yield $f = 0.92$.

Table 2 gives the resultant mass interior to 3′. For completeness, two values of the circular velocity have been used: 350 ± 15 km s^{-1} based on the H I profile, and 300 ± 20 km s^{-1} based on the stars (columns [2] and [3]). For reasons discussed in § III, the H I velocity is to be preferred. The corresponding mass-to-light ratios in blue light are given in columns (4) and (5). The error estimates in the table include the effect of uncertainties in the velocities only.

By assuming that all the mass belongs to the spheroidal component, one can place an upper limit to M/L_B for the spheroidal component alone (Table 2). This value is 3–4. M/L_B has been estimated by Williams (1976) for the nuclear region, using the central stellar velocity dispersion plus van Houten's luminosity profile near the nucleus. He finds 13.5 (corrected to our assumed distance of 18.6 Mpc). The disagreement between our value and his is not serious in view of the great difference between our techniques, together with the uncertainties inherent in the nuclear photometry.

The Sa galaxy NGC 681 bears a strong structural resemblance to NGC 4594 in having a very pronounced nuclear bulge embedded in a thin, dusty disk seen nearly edge-on. A rotation curve for this galaxy based on the Hα and [N II] λ6584 emission lines has been presented by Burbidge, Burbidge, and Prendergast (1965). From their data, we have determined a mass and M/L_B for the galaxy within a radius of 47″ (the radius of the dusty disk), using the same procedure we applied to NGC 4594. M/L_B for both components, bulge plus disk, is 3.4 ± 0.7, in good agreement with our value for NGC 4594. NGC 681 is thus another example of a galaxy with a prominent bulge component and yet a fairly low mass-to-light ratio.

Since the spheroidal components of NGC 4594 and NGC 681 strongly resemble normal elliptical galaxies in many respects, it is reasonable to compare their mass-to-light ratios with those measured for elliptical galaxies. The values of M/L_B near 3–4 in these two objects are much lower than the canonical values of 20–30 often assumed for elliptical galaxies but are close to the recent nuclear values for E galaxies determined by Faber and Jackson (1976) and by Williams (1976), which average around 7.[4] As is well known, the motions of ellipticals in binary pairs and in clusters imply much larger mass-to-light ratios of over 100 (e.g., Rood *et al.* 1972; Turner 1975). If all these disparate measurements are taken at face value, one is led to the conclusion that M/L increases dramatically with radius, as has been pointed out recently by Ostriker, Peebles, and Yahil (1974). The question then naturally arises: At what radius does this increase in M/L set in? The present observations of NGC 4594 are useful in this context because they imply no discernible increase in M/L over the easily visible halo. If NGC 4594 is typical, increases in M/L, if they occur, are to be found only at very low surface brightness, where they will be difficult if not impossible to measure directly.

V. GAS-TO-DUST RATIO AND STAR-FORMATION RATE

In Paper I, we pointed out that the small gas content of NGC 4594 was surprising in view of the large amount of interstellar dust that is present. We here revise our earlier conclusions, basing our revision on a more careful estimate of the optical depth in the absorbing layer, which can be obtained from van Houten's photometry of the dark band. In the darkest part of the band, the visual absorption is greater than or equal to 2.16 mag. Correcting for inclination, one finds that the optical depth perpendicular to the layer is greater than or equal to 0.26 mag. (This value is a lower limit because some of the light may originate in the dusty layer and in the foreground as well, making the dark minimum appear too bright.)

[4] Values of M/L_B in this paper are on the same scale as those in Faber and Jackson (1976) and should be directly comparable.

We assume that the layer is homogeneous, has an inner radius of 1.'5, an outer radius of 3', and a gas-to-dust ratio like that in the solar neighborhood. Using the relation $N_{\rm H\,I} = 1.7 \times 10^{21} \times A_V\ \rm cm^{-2}$ (Savage and Jenkins 1972), we find that the gas content expected from the dust layer is $2.2 \times 10^9\ M_\odot$. This is a factor of 2.5 times larger than the amount actually observed but is 4 times smaller than the amount stated in Paper I. Part of the difference is due to a misprint in Paper I, and part is due to our revised estimate of the optical depth, which is smaller here by a factor of 2.

In view of the uncertainty in the assumed gas-to-dust ratio as well as a possible underestimate in the H I mass owing to self-absorption (see § I), this difference between the expected and observed H I masses is probably not serious. Let us assume it is real, however, in order to estimate the observable consequences. In that case, the "missing" hydrogen may be present in molecular rather than atomic form, and CO emission may be expected, since it has been detected in other galaxies like M82 and NGC 253, which have prominent dust absorption (Rickard *et al.* 1975; Solomon and de Zafra 1975). Suppose all the missing hydrogen were present in dense clouds having masses and densities like those of the "standard galactic cloud" described by Solomon and de Zafra. The upper limit to the antenna temperature expected on the NRAO 11 m antenna is then $\sim$0.02 K, based on an assumed velocity width of 200 km s^{-1} in the 1' beam of the telescope. This value is less than our observed upper limit of 0.1 K described above. Hence our negative CO detection seems consistent with the observed amount of dust in NGC 4594, provided, of course, that the CO emission regions resemble those in our own Galaxy—a very difficult assumption to verify.

Of particular interest to the morphology of galaxies is the question of whether significant star formation is currently taking place in the dusty disk of NGC 4594. The evidence bearing on this point is contradictory. On the one hand, photoelectric measurements along the major axis (van Houten 1961) yield an average $B - V$ color index of roughly 0.7 in the disk. Since up to half the light may in fact be emitted by halo stars that have a color index close to 1.00, the disk must be significantly bluer than the bulge. There also exist blue knots and condensations in the disk which were interpreted by Sandage (1961) as filamentary spiral arms. Van den Bergh (1976) has suggested that these knots consist of blue stars. Both the knots and the blue color index indicate the presence of young, blue stars in the disk.

On the other hand, Münch (1962) attempted to detect ionized gas and H II regions in the disk but was unable to find any trace of emission. There is likewise no sign of emission in our image-dissector scans. Furthermore, the absorption-line spectrum of the disk from our data is characteristic of an old stellar population. The G band, Mg *b*, and Na D are all prominent, and there is no sign of enhanced Balmer absorption, which is a fairly sensitive indicator of massive young stars.

In view of the complicated effects of the dust absorption on the colors, it would be difficult to construct a quantitative model for the stellar population that incorporated all this information. However, it seems clear that, while some star formation may be taking place in NGC 4594, the general level of high-mass star-formation activity is fairly low, at least in comparison with later-type spirals. This apparent absence of intense star formation may be related to the comparatively low H I density. If one assumes that the H I is uniformly distributed in a disk like that described above that has a thickness of 1 kpc (corresponding to the vertical thickness of the dark band), the density of H I is less than one-tenth the solar neighborhood value of approximately 1 cm^{-3} (Allen 1973). (This estimate, of course, neglects a possible contribution from H_2 and is furthermore highly uncertain, since the volume of the gaseous disk is poorly known.) Alternatively, the star-formation rate may be considerable, but the initial mass function might be shifted toward lower-mass stars. This possibility has been suggested by van den Bergh (1976).

We noted above that the morphological appearances of NGC 4594 and NGC 681 are strikingly similar, yet the two galaxies differ significantly in their star-formation properties. Unlike NGC 4594, the disk of NGC 681 is filled with H II regions (Burbidge, Burbidge, and Prendergast 1965), where considerable star formation must be taking place. A more detailed knowledge of the gas densities in the two systems might help to explain this puzzling and possibly important difference.

VI. SUMMARY AND CONCLUSIONS

NGC 4594 is a useful object for study because it provides a relatively clean method for determining the mass-to-light ratio for an elliptical-like spheroidal stellar population at distances far from the nucleus. Based on the circular velocity measured for the gas, we set an upper limit to M/L_B for the spheroidal component of 3–4 within 3'. This low value implies that there is no measurable increase in M/L away from the nucleus out to the edge of the easily visible galaxy. If a significant increase in M/L_B does occur in the halo of this object, it must take place beyond 3' at very low surface brightness.

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