I THE SMOOTH BACKGROUND

"When you subtract everything that doesn't look smooth, you are left with a smooth background"

G. Westerhout at buffet dinner

THE DISTRIBUTION OF LIGHT IN GALAXIES

K.C. FREEMAN
Mount Stromlo and Siding Spring Observatory,
Research School of Physical Sciences,
The Australian National University.

The distribution of light in galaxies is their most obvious and fundamental observable property. Hopefully it gives us some insight into their structure and dynamics. In this talk I will review some recent work on ellipticals and disk galaxies. In summary, the luminosity distributions for both these classes have several complexities, the dynamical significance of which is not yet clear. Both classes turn out to have roughly constant mean surface brightness. This may result from selection. However, if it is real, then it is important dynamically, and I will discuss this question at the end.

1. ELLIPTICALS

Ellipticals have a wide range of absolute magnitudes, and it seems clear that the structure changes with magnitude. The normal giant ellipticals ($M_B \leq -18$) have roughly similar radial surface brightness distributions I(r). These I(r) distributions can mostly be represented fairly well by King's (1966) models with $\log(r_t/r_c) \approx 2.2$. These models were originally constructed to represent globular clusters. They are a one-parameter family of truncated isothermal spheres, whose central concentration increases with increasing values of r_t/r_c (tidal radius to core radius): the limit is the isothermal sphere itself. Alternatively, two empirical laws are often used. One is de Vaucouleurs' well known $r^{\frac{1}{4}}$ law

$$\log I(r) \propto r^{\frac{1}{4}}$$

which has no free parameters. The other is the truncated Hubble law

$$I(r) = I_o(r+\beta)^{-2}\exp[-(r/\alpha)^2]$$

E. M. Berkhuijsen and R. Wielebinski (eds.), Structure and Properties of Nearby Galaxies, 3-14. All Rights Reserved.

introduced by Oemler (1976), where α and β are length scales. This is again a one-parameter (α/β) family of increasing central concentration, like the King family.

There is evidence now that the I(r) profiles for normal ellipticals may depend on their environment. For example, Strom's (1977) photometry of ellipticals in the Coma cluster shows that the brighter systems ($M_B<-21$) in the outer parts of the cluster have more extended envelopes than the ellipticals in the inner parts. This is probably due to tidal processes. Similarly the dwarf ellipticals ($M_B>-16$) are significantly less centrally concentrated than the giants, and this is again presumably tidal. Their I(r) distributions are well fitted by King models with log (r_t/r_c) in the approximate range 0.5 to 1.5. On the other hand, the cD ellipticals, which dominate some galaxy clusters, have very extensive outer envelopes. These may result from accumulated cluster debris, or from the cD galaxies themselves forming through mergers of smaller galaxies. This question is not settled yet.

Now we come to the shape of ellipticals. The belief is that ellipticals are oblate spheroidal systems, flattened presumably because they are rotating. With the assumption of oblateness, we can infer the true distribution of axial ratio from the apparent distribution. It turns out that the true distribution is peaked at axial ratio 0.6, with very few truly spherical systems, and none flatter than axial ratio 0.3. However reality seems more complicated. (i) The isophotal eccentricities of ellipticals change with radius. King's results, quoted by Wilson (1975), show that e(r) can be monotone increasing or decreasing, or take a maximum or minimum at intermediate radii. There is also evidence that the position angle of the major axis changes with radius. (ii) Observations of rotation curves for several flat ellipticals, by Bertola and Capaccioli (1975) and Illingworth (unpublished), give peak rotational velocities much smaller than expected. There are several possible interpretations of (i) and (ii), taken together. They certainly suggest that rotation and flattening are not uniquely related, and that ellipticals may be triaxial or even prolate. This now has some theoretical support. Binney (1976) has shown how the dissipative collapse of a galaxy can lead to an eccentricity independent of rotation, and Miller's recent N-body results show how triaxial systems can form during the collapse of a stellar system. Observations of the distribution of apparent axial ratio for ellipticals are not inconsistent with the concept that ellipticals are prolate systems. A true distribution peaked near axial ratio 1.8, with few systems more elongated than axial ratio 2.5, and again with very few truly spherical

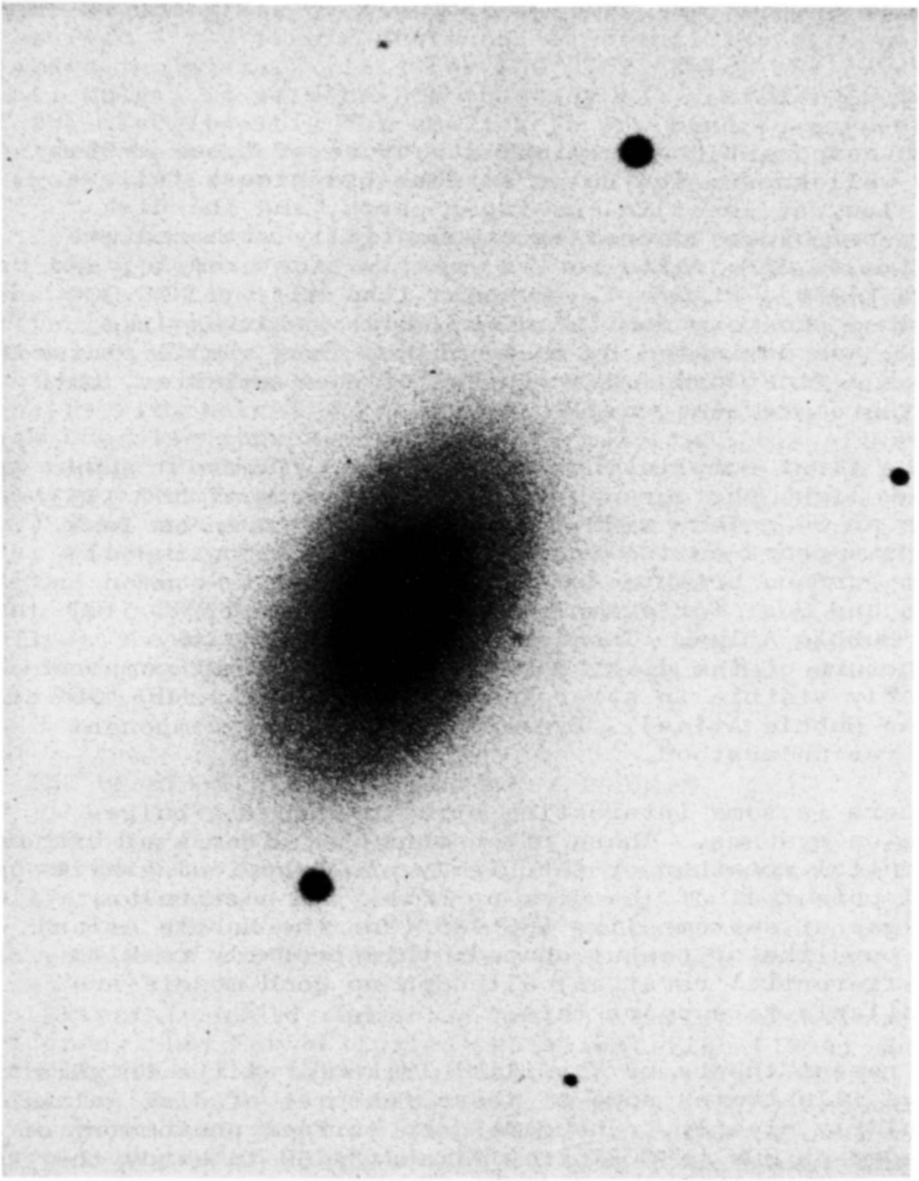

Figure 1: Yellow light photograph of the SO galaxy NGC 1553. Note the prominent lens.

systems, represents the data just as well as the distribution of oblate systems discussed earlier.

2. DISK GALAXIES

The two-component (bulge+disk) structure of these systems is now well known. The bulge surface brightness follows the $r^{\frac{1}{4}}$ law, at least in the inner parts, and the disk surface brightness decreases exponentially with radius. The bulge to disk ratio varies greatly: for example, see Freeman (1974), Figure 1. Systems like M33 and NGC 300 are almost pure exponential disk, while galaxies like NGC 4594 are dominated by their bulge. This simple picture provides a first order description of disk galaxies, but again there are some complications.

The first complication is the lens. Figure 1 shows a yellow light photograph of the inner parts of NGC 1553. This is an SO galaxy with a particularly prominent lens. The lens appears as the annular region of approximately uniform surface brightness. This structure is common in spirals and SOs: for examples, see NGC 210 and NGC 5101 in the Hubble Atlas. The lens is almost certainly a substructure of the disk, because a similar flat component is clearly visible in several edge-on SOs, like NGC 4762 (see the Hubble Atlas). Dynamically the lens component is not yet understood.

There is some interesting structure in the bulges of edge-on systems. These often show the effects of either differential rotation or the highly non-spherical gravitational potential of the disk or both. In particular, the bulges of systems like NGC 128 (see the Hubble Atlas) appear box-like or peanut shaped: this probably results from differential rotation, although no good models are yet available to support this.

A recent thesis by Vassiliki Tsikoudi at the University of Texas illustrates some of these features of disk galaxies particularly clearly. She made deep surface photometry of three edge-on SOs (NGC 4762, 4111 and 3115) to study the structure of the bulge and disk. We can summarise the main important results. (i) Along the major axis of these galaxies (ie along the edge-on disk), the surface brightness does not decrease smoothly with radius, as we would expect for a purely exponential disk. Two or three plateaux are seen, the inner one corresponding to the obvious lens component in photographs. These plateaux appear symmetrically on both sides of the nucleus, so they are most likely to be annular structures. (ii) Along the minor axis, the bulge follows the $r^{\frac{1}{4}}$ law in the inner parts, but further out there is an excess of light above this law. The difference, (observed - $r^{\frac{1}{4}}$) itself decreases exponentially with height z above the plane. (iii) For NGC 4762, which has a very small bulge, it is possible to study the vertical structure of the disk itself. For small z (a few hundred parsecs), the surface brightness is a gaussian function of z; for larger z it is well represented by an exponential.

Two comments. (i) The z-structure of both the bulge and the disk shows an exponential decrease of surface brightness with z for large z. This makes sense. We know that elliptical galaxies are well represented by the King models, which are weakly truncated isothermal spheres. We know also that the isothermal sheet has an exponential decrease of density with height for large z. So, if the bulge and the disk are also approximately isothermal, then the effect of the rather flat equipotentials of the disk itself will lead to an exponential structure at large z, as observed. (ii) Some new results on the radial distribution of globular clusters in M87, NGC 4594 and the Galaxy (Harris and Smith, 1976; Wakamatsu, 1977; de Vaucouleurs, 1977) show that the surface number density of globular clusters also follows the bulge's $r^{\frac{1}{4}}$ law. This very clearly identifies the halo population (as defined by the globular clusters) with the outer bulge population.

3. THE CONSTANT SURFACE BRIGHTNESS PROBLEM

The problem here is that both ellipticals and disk galaxies appear to have approximately constant mean surface brightness (different values for the two classes). Is this real, or is it just the result of selecting galaxies of approximately the same mean surface brightness for surface photometry ?

First I should summarise briefly the observational evidence. (i) For elliptical galaxies, Fish (1964) showed directly that the total luminosity is proportional to the effective area. Also, Faber and Jackson (1976) and others have shown that the total luminosity is proportional to v^4, where v is the stellar velocity dispersion. Again, simple dynamical arguments show that this implies constant mean surface brightness. (ii) For the disk component of disk galaxies, the surface brightness follows the exponential law $I(r) = I_o \exp(-\alpha r)$. Freeman (1970) showed that, for systems with detailed surface photometry at that time, I_o was approximately constant, at 21.6 ± 0.3 B mag arcsec^{-2}, after correction for inclination and galactic absorption. Most recent deep photometry of disk galaxies confirms this result, except for dwarf systems which have fainter I_o.

Kormendy (1976) argues that this apparent constancy of I_o has no physical significance, but results merely from the contribution of the bulge in the outer parts of the galaxy where the exponential disk seems best defined. This seems unlikely, however, because (a) the constant I_o is seen also for systems like M33 and NGC 300 which have very weak bulges, and (b) much of Kormendy's photometry was for galaxies with prominent lenses, and did not always go faint enough to define the exponential disk properly.

This constancy of mean surface brightness (which also implies constancy of mean surface density because the M/L ratios are now known not to vary greatly) is dynamically important if it is real. For ellipticals, Fish showed that it is associated with a particular potential energy - mass relation, which contains useful information about the energy radiated away during the collapse phase, before star formation occurred. For the disk galaxies, the constant I_o means that the disk angular momentum is proportional to the 7/4 power of its mass, and this constrains angular momentum acquisition theories. De Vaucouleurs (1974) warned, however, that this constancy of mean surface brightness may just be a selection effect, associated with choosing galaxies against the night sky background, and Disney (1976) has recently given a compelling theoretical argument to support this view.

Disney assumes that galaxies are chosen for photometric programs by their radius (or area) at some limiting isophote corresponding to the detection level on photographic plates. For conventional blue light photographs against a dark sky, this isophote level is approximately $\mu = 24$ B mag per square arcsec. For a given total galaxy luminosity, there is some value of the mean surface brightness which maximises the radius or area of the galaxy within the $\mu = 24$ isophote. The particular value depends on the law for the radial surface brightness distribution: for $\mu = 24$, this corresponds to an exponential disk with $I_o = 21.6$, as observed, and also to an $r^{\frac{1}{4}}$-law system with the mean surface brightness observed by Fish. The picture is then that disk galaxies, for example, have a wide range of true I_o-values at a given total luminosity: only those with $I_o \approx 21.6$ are chosen for photometry because they are the largest in radius. Although Disney's argument strongly suggests that selection effects act in this way, because it reproduces the observed mean surface brightnesses so well, I think this may be fortuitous, for the following reasons.

(i) The preferred value of I_o depends on the value of μ set by the emulsion - night sky brightness combination. As mentioned above, $\mu \approx 24$ for blue IIa-0 exposures against a dark night sky, and the corresponding preferred value of I_o is about 21.6, as observed. Until recently, most galaxy photographs, including the Palomar Sky Survey, had approximately this value of μ. Now there is available the UK 48-inch Schmidt survey of the Southern sky, on IIIa-J emulsion, and this has $\mu \approx 26$. The largest galaxies at a given total luminosity then have $I_o \approx 23.7$. So, if Disney's hypothesis is correct, there should be many giant galaxies of relatively low surface brightness appearing on this survey, which does not appear to be so. The UK Schmidt survey does show many low surface brightness galaxies, but HI observations of these by members of the UK Schmidt unit and others in Australia suggest that they are mostly hydrogen-rich dwarfs.

(ii) The predicted value $I_o = 21.6$ for $\mu = 24$ depends also on the exponential form of the light distribution for disk galaxies. Although some systems have almost pure exponential disks, the surface brightness in most disk systems, at the $\mu = 24$ level, is dominated by the bulge or the lens. So if Disney's assumption is correct, that galaxies are chosen by their size at this level, then most are selected mainly by the size of their bulge or lens, for which the luminosity profile does not have the exponential form. The theory would then predict a value of I_o different from 21.6.

(iii) The observed I_o values for the exponential disks of disk galaxies are approximately constant only after correction for inclination and galactic absorption. The sample with corrected $I_o = 21.6 \pm 0.3$ included systems with uncorrected I_o values between 19.6 and 23.1. Obviously it is the uncorrected values that appear in selection procedures.

(iv) Although a particular mean surface brightness is preferred in Disney's picture, the selection effect is not strong enough to exclude from observation small systems of high surface brightness. Not many of these are known among the nearby galaxies; although the compact galaxies were possible candidates, recent work by Kormendy (1977) on red compacts and Rodgers (unpublished) on blue compacts shows that their surface brightnesses are fairly normal.

In summary, although there are certainly low surface brightness dwarf disk and elliptical galaxies, it appears unlikely to me that the apparent constant mean surface brightness (within each class) for giant galaxies results from selection effects. However this can now be tested directly, by choosing galaxies from the deep survey according to specific selection rules.

REFERENCES

Bertola, F. and Capaccioli, M.: 1975, Astrophys. J. 200, 439.
Binney, J.: 1976, Monthly Notices Roy. Astron. Soc. 177, 19.
de Vaucouleurs, G.: 1974, IAU Symposium No. 58, page 3.
de Vaucouleurs, G.: 1977, Astron. J. 82, 456.
Disney, M.J.: 1976, Nature 263, 573.
Faber, S. and Jackson, R.: 1976, Astrophys. J. 204, 668.
Fish, R.: 1964, Astrophys. J. 139, 284.
Freeman, K.C.: 1970, Astrophys. J. 160, 811.
Freeman, K.C.: 1974, IAU Symposium No. 58, page 129.
Harris, W. and Smith, M.: 1976, Astrophys. J. 207, 1036.
King, I.R.: 1966, Astron. J. 71, 64.
Kormendy, J.: 1976, Ph.D. thesis, Caltech.
Kormendy, J.: 1977, Astrophys. J. 214, 359.
Oemler, A.: 1976, Astrophys. J. 209, 693.
Strom, S. and Strom, K.: 1977, Preprint.
Wakamatsu, K-I.: 1977, Publ. Astron. Soc. Pac. 89, 267.
Wilson, C.: 1975, Astron. J. 80, 175.

DISCUSSION FOLLOWING REVIEW I.1 BY K.C. FREEMAN

TOOMRE: I would suggest that we deal with ellipticals first and with disks later.

STROM: I would like to point out that our analysis of $\sim$ 100 galaxies in the Coma cluster shows (1) the same range of $\varepsilon(r)$ characteristics (anything you can dream up!) as you report from Ivan King's sample, (2) in $\sim$ 10 - 15 per cent of our sample, a rotation of position angle of the major axis of the elliptical isophotes as one proceeds outward. These results as well raise the spectre of triaxial ellipsoids and/or bars in E-galaxies.

MILLER: In a paper in press we argue that ellipticals flatter than E2 are probably prolate objects. This is based on dynamical arguments, in that we have been unable to construct systems like ellipticals with axis ratios less than 2/3 that remain axisymmetric (oblate). Flatter systems are "unstable" to nonaxisymmetric disturbances, and ultimately form bar-like or triaxial forms that rotate about a short axis. Even so, ellipticals can show remarkably rapid rotation without much flattening. We have models with Ostriker-Peebles $t = T_{rot}/|W|$ of 0.17 that are nearly spherical, and systems with t as great as 0.27 that remain oblate. The system with t = 0.27 had about an E2 profile when viewed across the rotation axis. Systems that were spun even faster became bar-like.

A remarkable variety of forms has been obtained. For example, we have seen systems that resemble the Dedekind ellipsoids — figures stationary in space, but ellipsoidal in shape, supported by special particle motions.

HUNTER: My analysis referred to by Dr. Freeman is based on models for which the mass distribution function is assumed to depend only on the energy and the angular momentum about the axis of symmetry. Hence the possible effects of an extra integral of motion are ignored. The dynamical quantity that is significant in producing a distribution of oblateness (or prolateness) is the difference between the mean square velocity in the circular direction and that in the radial direction. Knowledge of this quantity alone does not allow any mean circular velocity of rotation to be deduced, because of the well-known insensitivity of the mass distribution to reversals in the directions in which orbits are described.

EKERS: The elliptical galaxies which have powerful radio lobes have a well defined axis which is presumably related to the ejection of the material which powers the radio source. If the apparent distribution of radio - optical major axes is analysed with the assumption that the elliptical galaxies are oblate and rotating about their minor axis then the radio axes are randomly distributed with respect to the rotation axes. A result which is somewhat difficult to reconcile with the constancy of the radio axis in time. However if the elliptical galaxies are prolate the analysis will be different and it is likely that the data is consistent with radio lobes aligned with the rotation axis.

MILLER: PROBLEMS IN GALACTIC DYNAMICS BY MEANS OF THREE-DIMENSIONAL SIMULATIONS

Computer simulations of galaxy models by means of n-body integrations are the only tools available for many problems in galactic dynamics. Long-range effects and collective effects can be followed into nonlinear ranges. A fully three-dimensional form is required to prevent unrealistic restrictions, especially if we hope to understand how galaxies can develop the remarkable symmetries shown by many observed objects. Large numbers of particles are required to separate dynamical and relaxation time scales. A fully three-dimensional simulation has been in operation on the ILLIAC IV computer at NASA-Ames Research Center for the past year. Simulations were based on 50 000 to 120 000 particles.

Motion pictures were shown for several classes of problems. These include: (1) Collapsing configurations started from a rigidly rotating sphere of uniform density. Within two free-fall times, runs started with different initial rotation speeds and different velocity dispersions all formed a prolate bar that rotated about a short axis. Some runs passed through intermediate stages in which a ring appeared briefly while others briefly showed sheets. These intermediate forms were too short lived to be of astronomical importance, but the bar is a long-lived form that may be important astronomically. (2) Particle motions in the bar. These bars are peculiarly stable, and may well represent barred spirals or prolate elliptical galaxies. There is pronounced streaming in the direction of rotation. Orbits have been studied, and rotation curves suitable for comparison with observation have been obtained. (3) Flattening of rotating systems. This investigation was undertaken to determine how flat an elliptical might be and still remain oblate. The flattest found so far is E2. These centrally condensed systems can rotate remarkably rapidly and still retain nearly spherical form. (4) Galaxy formation by collapse of gaseous spheres with star formation. Stars continue to form at about the same rate (relative to the amount of gas available from which to form them) and to deplete the gas to unacceptably low levels (1-2%). (5) Collision of pairs of galaxies. The transfer of energy from orbital motion to internal degrees of freedom is large, and leads to ejection of a surprisingly large number of stars. Orbital angular momentum is rapidly depleted in deeply penetrating collisions by means of ejected particles.

VAN DEN BERGH: Can one exclude the possibility that galaxies with "peanut-like" nuclear bulges are, in fact, objects in which we are looking almost along the axis of a bar?

FREEMAN: No, I don't think we can exclude that.

MARK: For axisymmetric fluid equilibria in differential rotation (specifically previously applied to rotating stars, Mark, J.W.-K., 1968, Ap.J. 154, 627), I have found that some of them are flatter at the polar axis than at some positive radii nearer the equator. These equilibria are stable as far as we know and they need only a two or three to one variation in rotation frequency from center to surface. Bulges of galaxies might well be exhibiting similar equilibria whose edge-on view would then be more box-shaped (versus spheroidal) or even bi-lobed (peanut-shaped). Presence of the flat disk might accentuate such behaviour and make them more observable.

BALDWIN: If one analyses the surface brightness in "peanut" structures as a function of R at constant z on the assumption of cylindrical symmetry, does it lead to a physically sensible distribution of luminosity? For example, is it everywhere positive?

FREEMAN: I have no idea.

EINASTO: Dr. Freeman indicated that in some galaxies (example VII Zw 303) the disk or lens should have a hole at the center. We have studied the mass distribution in our Galaxy (Tartu Astr. Obs. Teated No. 54, 3, 1976) and in M31 (Tartu Astr. Obs. Preprint A-4, 1977) with particular emphasis of the structure of the disk. For both galaxies two models have been calculated: (a) with a normal exponential disk, and (b) with a disk having a hole at the center. In the first case it is impossible to obtain a model circular velocity curve with a minimum at $\sim$ 2 kpc, in the second case the calculated curve represents well the observed minimum. It is well known that in Sa and Sb galaxies the hydrogen avoids central regions and forms a ring-like structure. If our interpretation of the velocity curve is correct, then we come to the conclusion that a gaseous disk from which disk stars have been formed has always had a ring-like structure. This means that all the proto-galactic matter with small angular momentum has been used to form the bulge and the halo of Sa and Sb galaxies and no gas with small angular momentum has been left over to form the central part of the gaseous disk.

BERMAN: I have recently examined a 3-dimensional computer model of a galaxy with a disk component, with a cutout center and a massive spherical bulge. This general structure lasts for many galactic years. The qualitative shape of the rotation curve agrees with the above shown by Dr. Einasto.

GALLAGHER: In regard to Dr. Freeman's comments about the universality of B(0) ∿ 21.5 for exponential disks, one way to select low surface brightness disks is to look for galaxies which seem to have excessive HI content for their optical characteristics. One such object is NGC 6902, a southern Sb which was previously classified as S0 due to the low surface brightness of the disk. However, surface photometry from CTIO 4 m plates shows B(0) ∿ 21.8. Thus where very different selection criteria were used to choose a galaxy for surface photometry, we get the usual result. It is also interesting to note that due to the large size of 6902, the galaxy is very luminous (M_B ∿ -22 for H_o = 50 km s^{-1} Mpc^{-1}), and it therefore does seem possible that we select against low surface brightness galaxies in searching for luminous systems.

WIELEN: In 1970, you were forced to introduce exponential disks of type II, which do not extend right into the center of the galaxy. You have not mentioned these objects today. What is your present opinion about these objects?

FREEMAN: The point was that if you extrapolated the exponential disk you had a hole at the center in the distribution of the surface brightness. I am sure now that that is due to the lens; all we do is taking a spheroid, adding on an exponential disk, and adding a lens structure on top of that.

WIELEN: Is the lens really a new, independent component of a galaxy, or can it be simply a perturbation of the disk? For example, is the thickness of the lens different from that of the disk? Perhaps the lenses are just positive deviations of surface density from the ideal exponential disks while the type II-disks represent the negative perturbations.

VAN WOERDEN: Do the brightness profiles of lenses indeed have their maximum away from the center? Hence, are lenses toroidal rather than spheroidal?

FREEMAN: Yes, probably, but it is in principle impossible to work it out. To do that the contribution of the bulge should be subtracted from the observed profile but we have no a priori knowledge about what the bulge is like.

MEBOLD: THE KINEMATICS OF THE LENTICULAR GALAXIES NGC 1291 AND NGC 1326

21-cm line observations of the galaxies NGC 1291 and NGC 1326 (van Woerden et al. 1976, P.A.S.A. 3, 68) with the Parkes 64-m telescope (HPBW = 15') have been used to determine the position angle PA(HI) of the maximum velocity gradient of the HI gas distribution. This position angle is of particular interest because the position angles PA(R) and PA(L) of the two main constituents of these galaxies, the outer ring and the inner lens-bar system, differ by about 90° for NGC 1291 and by about 60° for NGC 1326 (cf. the photographs and the more detailed discussion in Mebold et al. 1978).

We find that the HI gas distribution is sufficiently extended in both NGC 1326 (HPW of HI gas = 4 min) and NGC 1291 (HPW = 16 min) that a velocity gradient can be determined. For NGC 1291 we further find that a minimum of about 50% of the HI gas must be, and a maximum of 100% may be, located in the outer ring or even further out. For NGC 1291 we find that PA(HI) = 85° ± 10° is inconsistent with PA(L) ∿ 170°, but is consistent with PA(R) ∿ 80°. However, PA(R) is ill defined because the outer ring is nearly face-on (inclination $i \leq 10^{\circ}$). For NGC 1326 we find PA(HI) = 270° ± 15° which again is inconsistent with PA(L) ∿ 30°, but is consistent with PA(R) ∿ 90°.

We conclude that the lens in both galaxies is either a triaxial spheroid rotating about one of its minor axes or a rotational ellipsoid seen partially edge-on and rotating about an axis which is not aligned with that of the outer ring and the HI gas distribution.

KINMAN: THE DWARF SPHEROIDAL GALAXIES NEAR M31

The distribution of stars in the three dwarf spheroidal galaxies discovered near M31 by van den Bergh (1972, Ap.J. 171, L31) have been derived from counts by L.L. Stryker and the author using IIIa-J plates taken at the prime focus of the KPNO 4-m reflector. Although the UBK7 Wynne triplet corrector has an unvignetted field of radius ∿ 25 arcmin, seeing-dependent corrections to the star counts must be applied which can critically affect the distributions obtained for radial distances exceeding 10'. These corrections are particularly important where, as here, the brightest stars are close to the plate limit (B ∿ 23), and the systems have a limiting radius (r_t) ∿ 15'. The determination of the core radius (r_c) requires the faintest limiting magnitude that is consistent with a resolution which minimizes the confusion from crowding. This was achieved by the microphotometry of the three best plates of each galaxy. The array of densities from each plate was combined on a computer and adjusted to increase the contrast in a selected range of densities before being converted back to a photograph which was optimized for star counting. Provisional results for Andromeda II show r_c ∿ 1.2', and r_t ∿ 15.5', which correspond to 240 pc and 3.0 kpc at a distance of 700 kpc. The central surface brightness is ∿ 24.7 V-mag per square arcsec giving an apparent V-magnitude of 13.0 and M_V ∿ -11.3; this is similar to Leo I in our Galaxy (Hodge 1971, Ann. Rev. A.A. 9, 35).