THE STELLAR KINEMATICS OF ELLIPTICAL GALAXIES

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ABSTRACT. The kinematic properties of elliptical galaxies are summarized. New developments are discussed in four areas: (i) the Faber-Jackson relation and the role of second parameters (ii) the luminosity-rotation relation (iii) the figures of elliptical galaxies and (iv) the mass-to-light ratio as a function of radius.

1. INTRODUCTION

Earlier reviews of this subject are found in the Proceedings of IAU 100 by Illingworth (1982) and in the Annual Reviews of the same year by Binney. The low rotation velocities of luminous ellipticals (say, $M_B < -20.5$, where I will use $H_o = 50$ km s^{-1} Mpc^{-1} throughout) were discovered by Bertola and Capaccioli (1975) and Illingworth (1977). This result is illustrated in Figure 1 which plots the ratio of rotation velocity over velocity dispersion as a function of ellipticity. The open circles scatter below both the mean expected line for oblate galaxies with isotropic velocity distributions and the median line for prolate isotropic galaxies taken from Binney (1978). Binney concluded that luminous ellipticals are not flattened by rotation, but by anisotropic pressures and therefore do not necessarily have spheroidal figures, but may be triaxial.

In 1982 Kormendy and Illingworth studied the bulges of 8 edge-on spiral galaxies. They discovered that, unlike the ellipticals, these bulges had rotation velocities and flattenings consistent with them being oblate, isotropic rotators. This result was confirmed by Dressler and Sandage (1983). Davies et al. 1983 (hereafter DEFIS) studied a sample of 11 low luminosity elliptical galaxies, $-18 < M_B < -21$ and found that they too had kinematics consistent with being oblate figures with isotropic residual velocities that are flattened by rotation. These results are summarized in Figure 1, in which lower luminosity ellipticals are shown as filled circles and the Kormendy and Illingworth bulges as crosses.

T. de Zeeuw (ed.), Structure and Dynamics of Elliptical Galaxies, 63–77.

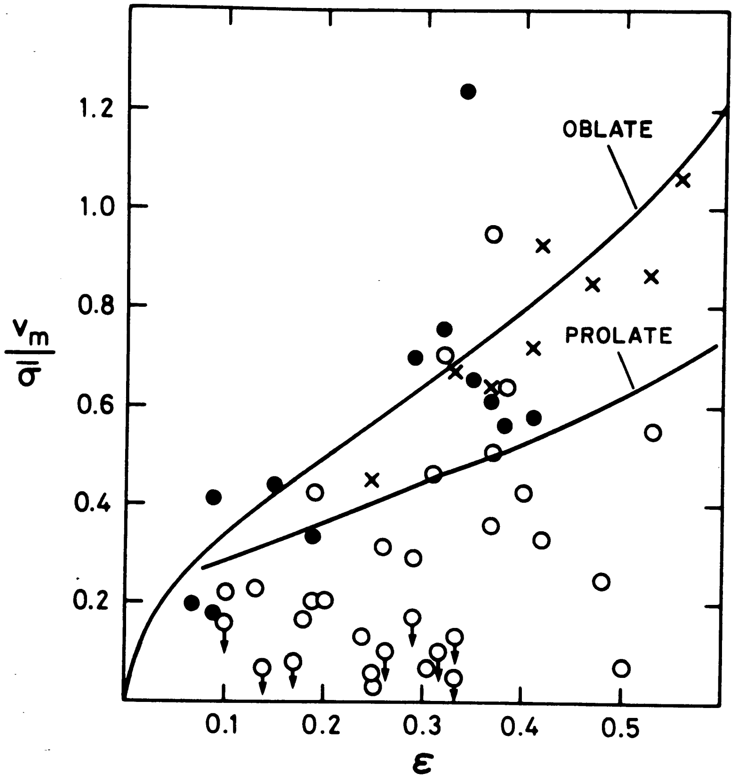

Figure 1: Peak rotation velocity plotted against velocity dispersion; open circles are luminous ellipticals ($M_B < -20.5$), filled circles are lower luminosity ellipticals and crosses are the bulges of spirals [this figure adapted from DEFIS]. The mean line for oblate isotropic galaxies and the median line for prolate isotropic galaxies are shown.

In this review, the observations on stellar kinematics of ellipticals are discussed with regard to four areas within which substantial progress has been made over the last four years:

(i) The Faber-Jackson relation and second parameters.
(ii) Further work on the rotation of early-type galaxies, as a function of luminosity.
(iii) The figures of elliptical galaxies - are they all consistent with being oblate or oblate-triaxial?
(iv) Do ellipticals have constant mass-to-light ratio as a function of radius?

These areas comprise sections 2-5 of this paper, Section 6 presents the conclusions.

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2. THE FABER-JACKSON RELATION

The relationship that the luminosity of an elliptical galaxy varies as the fourth power of velocity dispersion, $L \propto \sigma^4$, discovered by Faber and Jackson (1976) has been the subject of much discussion, mostly in the context of generating a distance indicator for ellipticals. In 1981 Terlevich *et al.* used a small sample of well studied galaxies to demonstrate the presence of a 2nd parameter in the FJ relation by noting that, at a given luminosity, galaxies with high values of velocity dispersion also possessed high values of the Mg_2 line index. They suggested that the second parameter was closely related to the intrinsic flattening of galaxies. In the same year, Tonry and Davis used the FJ relation on a large sample of ellipticals to measure local non-uniformities in the Hubble flow, in particular the motion of the Local Group toward the Virgo cluster. Their data confirmed the presence of a second parameter, but did not verify the correlations of Terlevich *et al.* in detail. In 1982 de Vaucouleurs and Olson showed that both color and surface brightness were significant second parameters in a study of 157 galaxies. Efstathiou and Fall (1984) proposed that mass-to-light ratio (M/L) was the second parameter as a result of a principal component analysis of the 67 Tonry and Davis galaxies and an extended sample (35 galaxies) similar to that of Terlevich *et al.*

Recently, the results of the expanded follow-up study to that of Terlevich *et al.* have been presented by Dressler *et al.* (1986). They find that the scatter in the FJ relation can be considerably reduced by using D_Σ, the diameter within which the mean surface brightness is $\Sigma = 20.75$ mags arcsec^{-2}, with the relation:

$$D_\Sigma \propto \sigma^{4/3} \qquad (1)$$

being the best fit to the data. They demonstrate that elliptical galaxies populate a plane in the 3-space of absolute magnitude (M_B), $\log\sigma$ and μ_e and demonstrate that the relation (1) produces the minimum scatter in D_Σ. They derive a form of the FJ relation based on (1) explicitly including the effect of surface brightness as a second parameter:

$$L \propto \sigma^{2.65} \langle SB_e \rangle^{-0.65} \qquad (2)$$

where $\langle SB_e \rangle$ is the mean surface brightness within r_e. A similar result has been found by Djorgovski and Davis (1986).

3. ROTATION

Davies et al. (1983) found that low luminosity ellipticals had kinematics consistent with them being oblate isotropic rotators. They concluded that the degree of rotational support decreases as luminosity increases. The mean relation was found to be $v/\sigma \propto L^{-0.4}$, although the rotational properties of luminous

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ellipticals are much less homogeneous than those of their fainter cousins. This situation is summarized in Figure 2 which shows $\log(v/\sigma)^*$, the ratio of v/σ measured, divided by that expected if the galaxy were an oblate isotopic rotator, against absolute magnitude, ellipticals are shown as filled circles, bulges as crosses. There are no faint galaxies with low values of $(v/\sigma)^*$. Plotted as open circles in Figure 3 are the cD and brightest cluster galaxies from the work of Tonry (1984,1985). These galaxies appear to behave like other luminous ellipticals showing a large scatter in the degree of rotational support, but in the mean having much lower normalized rotational velocities than would be expected for oblate/isotropic models. It appears that central cluster galaxies do not reveal their uniqueness by having exclusively low rotation velocities. The 3 galaxies in Tonry's sample with $\log(v/\sigma)^* > -0.2$ are the central galaxies in Abell 189, Abell 1228 (=IC738) and Abell 2151 (= NGC6041).

Whitmore, Rubin and Ford (1984) measured the stellar kinematics in the bulges of 6 spirals. They noted that the observations of Kormendy and Illingworth (1982) together with their own indicated that the bulges scattered just below the line of oblate isotropic galaxies in a plot of v/σ vs ε. They concluded that the bulges were not fully explained as oblate isotropic rotators. Recently, Jarvis and Freeman (1985) and Fillmore, Boroson and Dressler (1986) have self-consistently modeled their observations of the photometry and kinematics of the disks and bulges of spiral galaxies. They were able to account for the additional flattening of the bulge component due to the presence of the disk, an idea suggested by Monet, Richstone and Schechter (1981). Once this was taken into account, the bulges were found to be consistent with being oblate figures with isotropic velocity residuals. This is not to say that bulges or low luminosity ellipticals may not have some degree of triaxiality, only that it will be small.

Uncertainty over the definition of an elliptical galaxy has arisen because of the detection of dust and weak stellar disks in some ellipticals, e.g. Jedrzejewski (1985), Carter (1986). The surveys of surface photometry of ellipticals have revealed some galaxies with higher order distortions of their isophotes indicative of the presence of a weak disk. The most prominent such disk identified so far is that in NGC 4697 which Carter estimates contributes 2% of the total luminosity and 10-15% of the surface brightness where it is strongest. Such a galaxy with a bulge-to-disk ratio of 50 must surely still be considered an elliptical when discussing its global properties. However, the question arises: could a relation such as that shown in Figure 2 arise because weak disks are more common in low luminosity ellipticals and their presence biases the measurement of rotation velocity? The answer appears to be no; as a result of a surface photometry survey, Peletier _et al._ (1986) plot the amplitude of the $\cos 4\theta$ terms in the Fourier expansion of the isophote shape, B_4, as a function of absolute magnitude. This coefficient distinguishes disk-like distortions with the disk major axis aligned with the long axis of the ellipse from box-like distortions. They find no obvious excess of low luminosity galaxies

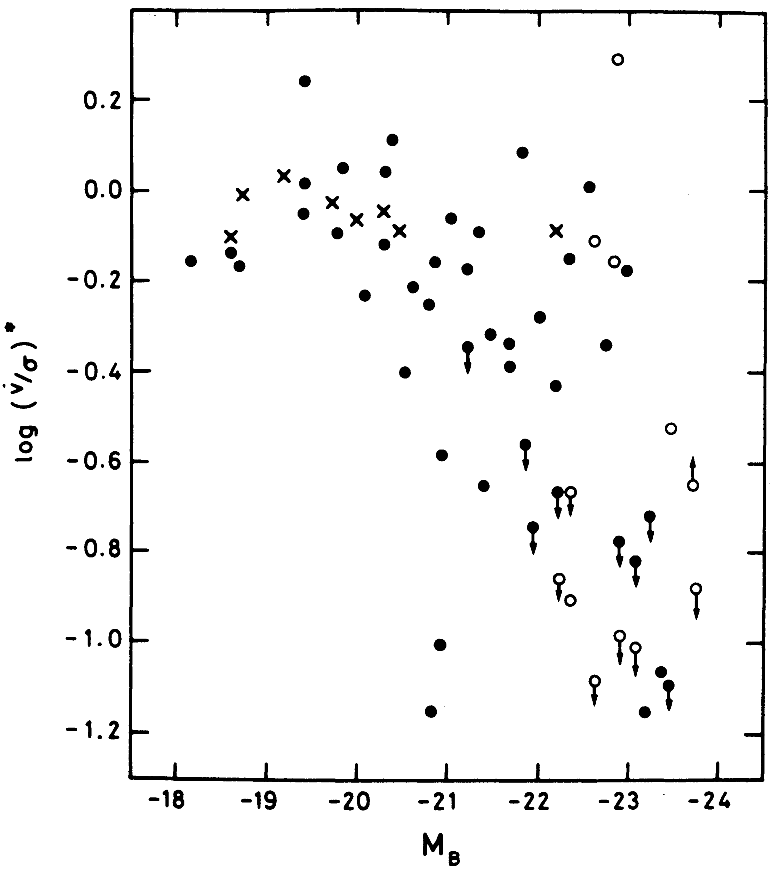

Figure 2: Log $(v/\sigma)^*$, the value of v/σ normalized to the value expected for oblate isotropic galaxies, plotted against absolute magnitude. This plot is taken from DEFIS with the cD and brightest cluster galaxies of Tonry (1984, 1985) added as open circles; filled circles are ellipticals and crosses are bulges.

with disk-like distortions; if anything an excess of boxes is indicated. A similar result is apparent in Djorgovski's thesis (1985) data on ~250 ellipticals. Plots of his higher order parameters as a function of luminosity indicate no trend with absolute magnitude except that the modulus of the amplitude of the higher order terms increases for the lower luminosity systems perhaps indicating that these are more easily tidally distorted than more luminous galaxies.

4. THE FIGURES OF ELLIPTICAL GALAXIES

The low rotation velocities of elliptical galaxies indicate that they are supported by anisotropic pressures and are therefore probably triaxial. Triaxial galaxies have the following properties:

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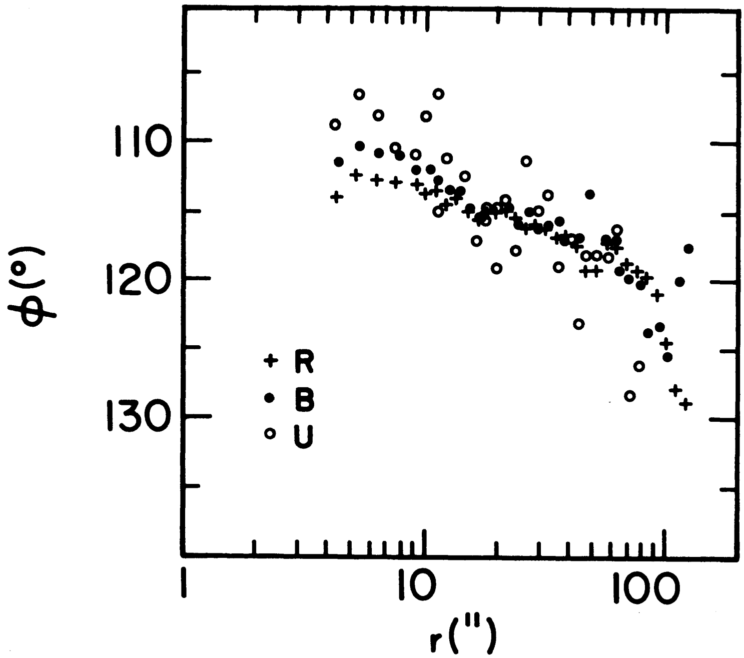

Figure 3a: Position angle as a function of radius taken for NGC 1052 taken from Davis et al. (1985).

(i) The projection onto the sky of concentric, triaxial ellipsoids with a radial gradient in axial ratio produce the appearance of an isophote twist.
(ii) Thus the projected minor axis does not have to be coincident with the projected kinematic minor axis, producing rotation on the apparent minor axis.
(iii) Schwarzschild (1979) showed that a triaxial figure has stable orbits that rotate about both the long and short axes, but that orbits rotating about the intermediate axis are unstable.

4.1. Velocity Mapping

Attempts to determine the figure types of ellipticals have involved mapping the stellar velocity field. In a study of twelve ellipticals hosting powerful ($\log P_{178MHz} > 24$ W.Hz^{-1}) radio sources, Heckman et al. (1985) used 2-3 slit position angles per galaxy and found no evidence for differences between the rotation and minor axes. Davies and Illingworth (1986) did an extensive study of the kinematics of the stars and gas in the active elliptical NGC 1052. The surface photometry of Davis et al. (1985) shows that this galaxy has an isophote twist that continues to radii as low as a few arcseconds (~500 pc). That isophote twist and the stellar kinematic data of Davies and Illingworth are reproduced in Figures 3(a) and (b). At

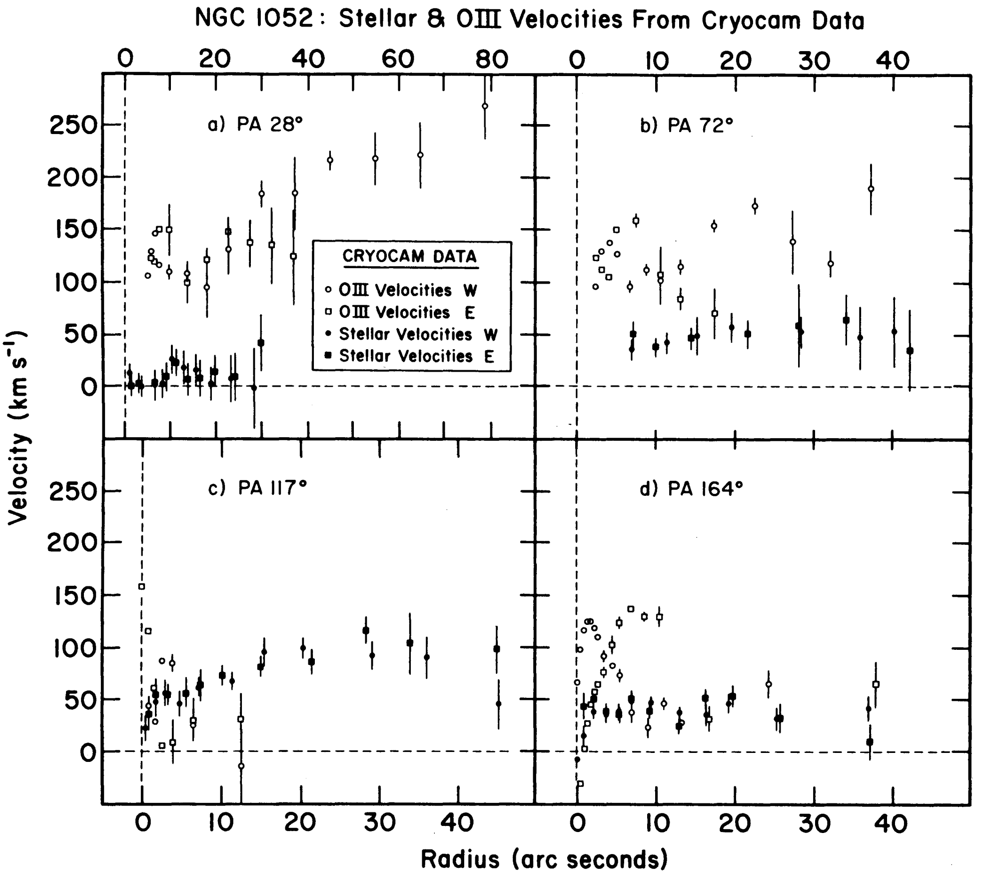

Figure 3b: The stellar velocities (filled symbols) and ionized gas velocities (open symbols) as a function of radius along the major axis (PA 117°), minor axis (PA 28°) and the two intermediate position angles in NGC 1052. (Figure taken from Davies and Illingworth 1986).

position angle 28°, on the photometric minor axis, between radii 10-25 arcsecs there is a shift in velocity seen on both sides of the nucleus (filled squares to the N, and filled circles to the S) indicating a small rotation of 10-15 kms^{-1} along the minor axis. These observations suggest that NGC 1052 is slightly triaxial and probably close to oblate, the difference between the rotation and minor axes being a few degrees at most. The kinematics of the ionized gas confirm this conclusion. In Figure 3(b) the open symbols give the velocities of the ionized gas along the four slit positions. A fit to a thin disk model at a radius of ~ 10 arcsec gives a projected rotation axis for the gas of -41°, that is 69° away from that of the stars. An aperture synthesis map of the HI gas in NGC 1052 has been reported by van Gorkom et al. (1986). This shows that the rotation axis of the gas disk at a radius of 2 arcminutes is -46°, almost

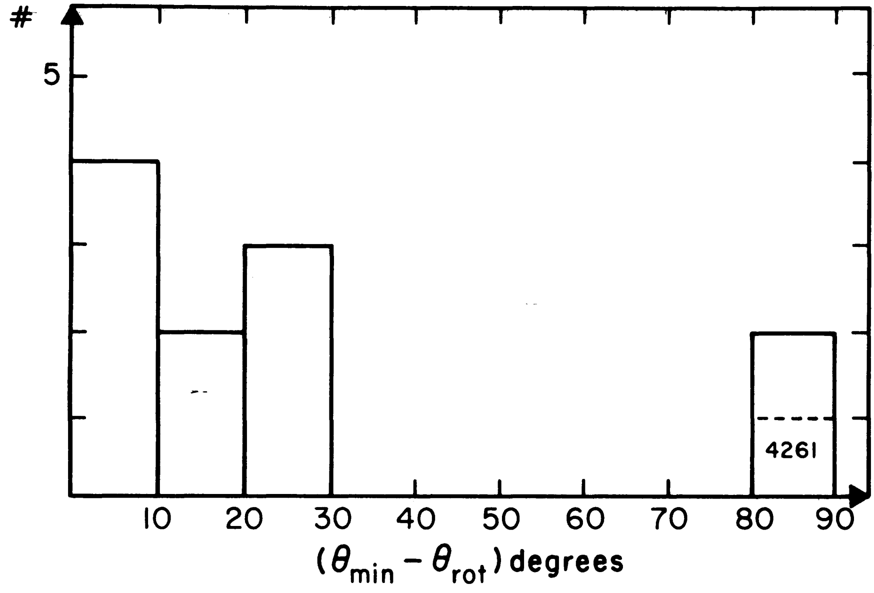

Figure 4: The histogram of the misalignment of the projected minor and rotation axis from the sample of ellipticals studied by Davies and Birkinshaw (1986b).

exactly that of the ionized gas at small radius. Thus the rotation axis of this gas disk remains constant over a factor of 10 in radius and is misaligned with that of the stars. If this gas disk were in a spheroidal galaxy the misalignment would cause the disk to precess, faster at smaller radii, and become warped. Thus the constancy of the rotation axis of the gas disk indicates that indeed NGC 1052 is triaxial and that the gas is rotating about the projected long axis.

In a survey of elliptical galaxies containing weak radio sources (median $\log P_{5GHz}$ = 21.7 $W.Hz^{-1}Sr^{-1}$) Davies and Birkinshaw (1986b) mapped each galaxy with at least four slits and used a kinematic model similar to that of Binney (1985) to determine the rotation axis. Their histogram of the difference between rotation axis and minor axis is shown in Figure 4 (NGC 1052 and NGC 5128 have been added to the sample and 2 galaxies with rotation axis orientations uncertain by more than 30° have been omitted). Most galaxies do not have a significant difference between their rotation and minor axes but at least one of these, NGC 1052, is thought to be triaxial. In addition, three galaxies have ($\theta_{min} - \theta_{rot}$) small but significantly different from zero. These results suggest that most ellipticals are triaxial but closer to oblate than prolate. NGC 4261 was found by Davies and Birkinshaw (1986a) to have a rotation axis 84° ± 4° away from its projected minor axis and to have no isophote twist and a second galaxy with much lower rotation velocity and thus more uncertain rotation axis also falls in this bin in their preliminary analysis. [Williams

(1981) discovered that NGC 596 displays a 60° isophote twist and rotates about an axis that changes with radius, but is nowhere coincident with the projected minor axis. He modeled it with a series of dissimilar nested triaxial ellipsoids and showed that at large radii it rotates about its long axis and is prolate. NGC 4261 shows no isophote twist and no change of rotation axis with radius]. It seems that at least NGC4261 is very likely to be prolate. Levison (1986) has shown that it is possible to populate the orbits of an oblate-triaxial galaxy to generate a streaming velocity about the major axis. This configuration seems less likely than a triaxial-but-close-to-prolate figure for NGC 4261. The data suggests that all ellipticals are triaxial with most being close to oblate spheroidal and a small fraction being close to prolate spheroidal.

4.2. Galaxies with Dust Lanes

For triaxial galaxies with warped minor axis dust lanes van Albada, Schwarzschild and Kotanyi (1982) and Merritt and deZeeuw (1983) showed that, for the dust to be on stable orbits, the action of the Coriolis force and the sense of the warp predicts the sense of figure tumbling. Steiman-Cameron and Durisen (1984) showed that there was a significant chance, 10-20%, that gas would be accreted onto stable orbits rotating about the long axis of a mildly triaxial figure (1:0.98:0.5) as a result of an interaction. Thus galaxies with minor axis dust lanes do not have to be prolate but can be triaxial and close to oblate (as appears to be the case for NGC 1052).

Davies et al. 1984, Bertola et al. 1985 and Wilkinson et al. 1986 applied this idea to NGC5128 (=Centaurus A) and discovered that the stars rotate in the opposite sense to that predicted for the figure. If we assume that models in which the stars counterstream with respect to the figure are unlikely, then this observation indicates that the dust in NGC5128 is not on stable orbits. A similar situation was found for NGC5266 by Caldwell (1984). Perhaps the question to ask now is: while the dust is not on orbits that are formally stable, what is the timescale for decay?

In their comprehensive study Wilkinson et al. put limits on the form of a stationary figure for NGC 5128, they showed that if the radio/X-ray jet is constrained to escape perpendicular to the dust lane along the long axis, the galaxy can be oblate triaxial. If that constraint is relaxed, they concluded that the figure could be prolate.

In this section examples of elliptical galaxies that are oblate (the low luminosity ellipticals), oblate/triaxial (NGC 1052, NGC 5128) and prolate/triaxial (NGC 4261, NGC 596) have been identified and it appears that the oblate and triaxial-but-close-oblate galaxies are a significant majority. A small fraction of ellipticals are prolate triaxial. The configurations that are close to spheroidal, either oblate or prolate, may be preferred over more triaxial (b = 1/2(a+c)) figures, but many more galaxies need to be mapped to firmly establish this.

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5. MASS TO LIGHT RATIO AS A FUNCTION OF RADIUS

5.1. Halos

5.1.1. Stellar Velocity Dispersion as a function of Radius.

Do elliptical galaxies possess high M/L halos analogous to those surrounding spirals? In the specific case of central cluster cD galaxies: does M/L at large radius reach the values inferred from the motions of the galaxies in the cluster, namely $M/L_B \sim 10^2 - 10^3$. Stellar kinematic data on cD galaxies collected by by Dressler (1979) on IC1101 in the center of Abell 2029, Carter et al. (1981) on IC 2082, Davies and Illingworth (1983) on NGC4889 and NGC4839 and Carter et al. (1985) on 0559-40, PKS 2354-35 and Sersic 40/6 indicate that the velocity dispersion as a function of radius is either constant or rising. Dressler interpreted the rise in velocity dispersion in IC 1101 as evidence for a high M/L component, but Tonry 1983 pointed out that the data could be fitted with constant M/L by increasing the tangential component of the velocity dispersion with radius. This model for IC 1101 required $\sigma_t = 3.7\ \sigma_r$ at the limit of the kinematic data. Subsequent work has recognized the difficulty in assigning a unique interpretation to the dispersion profiles. Several general points are clear:

(i) In models of cDs in clusters with a third component in addition to the stellar galaxy and cluster, that component has an M/L and lengthscale between those of the luminous galaxy and the cluster.

(ii) The local M/L implied at large radius is 2-5 times the central value, so the high cluster values are not directly indicated.

(iii) In all but 2 cases, IC1101 and Sersic 40/6, the dispersion profile can be fitted with $\sigma_t < 2.5\ \sigma_r$ and constant M/L.

(iv) While only the cD galaxies show increases in velocity dispersion with radius (the best 2 examples being those in (iii)) many normal ellipticals have σ(r) approximately constant. There is no reason to believe that those cDs with σ(r) ~ constant are particularly unusual.

5.1.2. The Velocities of Multiple Nuclei. The well known large relative velocities ($\Delta v \sim 1000$ km s^{-1}) between central cluster galaxies and the multiple nuclei embedded in their images led to the idea of very large M/L for these galaxies. This phenomenon is common; Schneider, Gunn and Hoessel (1983) find multiple nuclei in 45% of brightest cluster galaxies. Blandford and Smarr (1983) suggested the idea of deep potential wells in clusters to account for those observations, the so-called "black pit" hypothesis. However, Tonry (1984, 1985) found that, at the radii of the multiple nuclei, the galaxy velocity dispersions were much too low to account for the large relative velocities of the nuclei if they were on circular orbits. He concluded that the nuclei are on highly radial orbits with high line-of-sight velocities and that the M/Ls for cDs and brightest cluster galaxies were the same as those for normal ellipticals.

Merritt (1984) has shown that the effect on cluster evolution of the dynamical friction of galaxies with the background of dark matter is to increase the probability of finding a galaxy very close to the cluster center by a factor of 3 without significantly reducing their velocities. This provides an explanation of Tonry's observations without invoking cannibalism but rather a slower dynamical evolution of clusters.

5.1.3. Other Methods. Dressler, Schechter and Rose (1986) used 6 satellite galaxies around the isolated elliptical NGC720. By comparing the mean projected radius and velocity dispersion of the satellite galaxies with that of the luminous galaxy they concluded that the mass interior to the satellites was 44 times greater than that of the luminous galaxy. Despite questions as to the physical association and orbit distribution of the satellites, if suitable candidate systems can be found this method appears to be a potential means of measuring the mass of ellipticals at large radii. In particular, it could provide independent mass estimates at large radius from those derived from the distribution of X-ray surface brightness.

It appears that the stellar kinematic tracers in elliptical galaxies do not extend far enough in radius to unambiguously detect the presence of a halo. Other methods discussed in this volume such as the presence of shells around ellipticals (Quinn and Hernquist), the velocity dispersion of globular clusters (Mould) and the surface brightness distribution of the X-ray gas (Fabian) provide more compelling evidence for increasing M/L with radius in ellipticals.

5.2 Central Mass Concentrations

The measurements of luminosity and velocity dispersion profiles for M87 by Sargent et al. (1978), Young et al. (1978) and Dressler (1980) have attracted considerable attention. Duncan and Wheeler (1980) pointed out that the inference of a central mass of 5×10^9 M_o was dependent on the assumption of isotropy of the stellar orbits. Binney and Mamon (1982) and Newton and Binney (1984) produced a model that was consistent with the observations and had constant mass-to-light ratio but required the radial component of dispersion to be more than twice the tangential component from 50–200 pc. At maximum the radial component was more than 3 times the tangential. More recently, Richstone and Tremaine (1985) used Schwarzschild's linear programming method to produce models of M87 with M/L_B constant (= 10 ± 2) and radial anisotropies typically less than a factor of 2. The conclusion that emerged was that a central mass in M87 is not required. However, work by Merritt and Aguilar (1985), Barnes, Goodman and Hut (1986), Binney and May (1986) and Palmer and Papaloizou (1986) has demonstrated that even modest radial anisotropies in spherical galaxies can be unstable to bar formation. The question of the stability of spherical galaxies with radial anisotropies of the size required by constant M/L models of ellipticals needs to be resolved.

Finally, other galaxies have now been observed sufficiently well to allow detailed modeling, NGC1052 by Davies and Illingworth (1986) and M31 and M32 by Kormendy, presented in this volume.

6. CONCLUSIONS

Elliptical galaxies populate a plane in the 3-space of absolute magnitude, M_B, log σ and μ_e demonstrating that surface brightness is the second parameter in the Faber-Jackson relation. A new distance indicator for ellipticals, D_Σ, the diameter within which the mean surface brightness is 20.75, has been shown to be optimum. The rms error on relative distances using this indicator are ± 25% for a single galaxy. Studies to utilize this to investigate non-uniformities in the Hubble flow are underway.

In the mean the degree of rotational support in elliptical galaxies decreases with luminosity. Luminous ellipticals ($M_B < -20.5$) have a range of rotational support from being consistent with oblate/isotropic to having rotation velocities a factor of 10 lower than expected under that hypothesis. The brightest cluster galaxies do not appear to be special in this regard. The question of the rotational properties of luminous bulges such as the Sombrero galaxy (M104) remains unanswered largely because such objects are so rare. Some ellipticals have been shown to possess weak disks but there is no evidence that the presence of such a disk significantly biases the observed kinematics, in particular these disks are not more frequent among low luminosity galaxies and there is no evidence to suggest they are more frequent among faster rotating ellipticals.

It appears that most ellipticals are triaxial and close to oblate with a small fraction being triaxial and close to prolate. The distribution of the differences of rotation and minor axes, ($\theta_{rot} - \theta_{min}$), suggests that forms closer to the spheroids are preferred over perfectly triaxial figures. Only a small number of galaxies have been kinematically mapped; many more are required to firmly establish this conclusion. If one is prepared to make assumptions about the 3D orientation of dust lanes or radio jets this extra information can be used to break the degeneracy of projection onto the sky and further constrain the figure types. As there are well-known cases of the bending of radio jets and warping of dust lanes this approach is not as secure as mapping the stellar velocity field.

The stellar kinematic evidence for an increasing M/L with radius in ellipticals is not decisive. Indications from globular clusters, shells, satellite galaxies and X-rays are more compelling. Evidence for central masses in elliptical galaxies is strengthened by the results on the rotation curve of M32 presented in this volume by Kormendy and by the realization that the radially anisotropic orbital configurations required for constant M/L models of M87 may be unstable.

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DISCUSSION

Gerhard: I would like to ask you more about NGC 1052, because it might be a galaxy for which the intrinsic axial ratios could be determined by the method described by Mario Vietri and myself in a poster paper outside. Three questions: (i) How detailed a velocity field do you have for this galaxy? (ii) What is its luminosity profile? (iii) What is the radial extent of the gas disk in terms of the scale of the luminosity profile?

Davies: The detailed answer to these questions can be found in *Astrophys. J.*, 1986, **302**, 234, and *Astron. J.*, 1985, **90**, 169. The stellar kinematics will be tabulated in a paper by Binney, Davies and Illingworth that is in preparation.

Capaccioli: NGC 4261 is a boxy galaxy. A few years ago we suggested that it might be an S0. We also know that there is another S0, NGC 4125, showing strong rotation along the photometric minor axis. In the second case there is no major evidence for triaxiality. Could you comment on that?

Davies: There is no reason to suspect that NGC 4261 is an S0. I believe the minor axis rotation in NGC 4125 is in the gas alone.

Kochhar: Why don't low luminosity ellipticals like to have velocity anisotropy?

Davies: Perhaps they have undergone more dissipation. I believe Ray Carlberg will say more about this.

Schechter: I think we must bear in mind that there are S0 galaxies with polar rings which slow significant misalignment with the intrinsic minor axis of the underlying galaxy. Linda Sparke has argued (1986, *Mon. Not. R. astr. Soc.*, **219**, 657) that these rings may be stabilized by their own self-gravity. The circumstances may be similar in some of the dust lane ellipticals, in which case dust lanes might not coincide with the symmetry axes of the underlying galaxy.

Davies: The polar ring galaxies are in general different from the disk we see in NGC 1052 in that they lie generally outside the optical image. In order to have a stable rotation axis over a factor of 10 in radius from the centre of the galaxy outward, the disk in NGC 1052 must have its angular momentum along a principal axis of a triaxial figure.

Jaffe: Does the similarity of form of spiral bulges, which we assume are contained in massive halos, and ellipticals, suggest that ellipticals are surrounded by halos?

Davies: No, in fact there is no evidence for significant dark matter within the luminous part of the galaxies, say within one effective radius.

Binney: At the sort of radii where the bulges can be seen, the work of Kent and others *strongly* suggests that the visible components are solely responsible for any galaxy's force–field.

Martin Schwarzschild and George Djorgovski.