Ellipticals with Kinematically–Distinct Cores: WFPC1 Imaging of Nearby Ellipticals[1]

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ABSTRACT

Ground–based spectroscopy of nearby ellipticals has revealed many to have cores that are kinematically–distinct from the rest of the galaxy. Spectroscopic line analysis suggests that these kinematically–distinct cores form a disk–like structure. A variety of mechanisms have been proposed to explain such cores.

Here we present high resolution WFPC1 imaging of several kinematically–distinct core galaxies to probe the relevant spatial scales and to search for a photometric counterpart to the kinematic component. Six of the eight galaxies examined here show clear indications of small–scale dust. This dust may be directly linked to the existence of nuclear radio activity in these galaxies. Due to the ubiquitous dust, it is difficult to detect photometric disks in most of our galaxies. The shape of the surface brightness profiles are similar to those seen in other 'kinematically–normal' ellipticals observed by *HST*. The derived density profiles are somewhat higher than those for compact, low luminosity galaxies. The fact that the surface density profiles are normal argues against formation scenarios in which small galaxies fall into big galaxies and dominate the light in the core region. Simulations with realistic density profiles and possible black holes would be valuable.

Subject headings: galaxies: elliptical, galaxies: nuclei, galaxies: individual

1. Introduction

Elliptical galaxies with stellar cores that are kinematically–distinct from the rest of the galaxy appear to be quite common and yet their origin remains somewhat of a mystery (Illingworth & Franx 1989; Bender 1990). Although it was originally thought that these cores could have formed from the capture of a small, compact companion (Kormendy 1984; Balcells & Quinn 1990), such mergers would predict a blue and metal poor core, which is generally not observed (Franx & Illingworth 1988; Bender & Surma 1992). It is perhaps more likely that in situ star formation has occured in kinematically–distinct gas (e.g. Schweizer 1990; Hernquist & Barnes 1991; Weil & Hernquist 1993). Recently, a new model to explain kinematically–distinct

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core ellipticals has been proposed by Hau & Thomson (1994). In this model the bulk of the elliptical galaxy halo is spun–up by a retrograde interaction with another galaxy. Alternatively, the cores may be built up from merging subclumps at the formation epoch of the galaxy. Streaming motions (Statler 1991) are another possibility, but these models can not explain the counter–rotating cores. Thus understanding the formation of kinematically–distinct cores will have a direct bearing on the formation and evolution of elliptical galaxies.

Detailed analysis of the spectroscopic lines reveals that the velocity distributions of the stars are strongly asymmetric in the core. These asymmetries have be modeled (Franx & Illingworth 1988; Surma 1992) by the combination of a hot, non–rotating and a cold, rapidly rotating component (i.e. a disk). Given this, high resolution imaging with *HST* could then be used to confirm the existence of such disks, and to obtain further data on their properties. At the very least imaging would reveal the stellar light distribution and that of any dust in the central region. These photometric properties can then be compared to galaxies with 'normal' kinematic properties.

Previous high resolution imaging with *HST* has revealed much structure in the central regions of nearby ellipticals that is not resolvable from even the best ground–based observatories (e.g. Lauer *et al.* 1991, 1992a,b; Crane *et al.* 1993; Forbes, Franx & Illingworth 1994; Jaffe *et al.* 1994). We have an on–going program to obtain *HST* Planetary Camera images of the central regions of kinematically–distinct core ellipticals. Our first results for the rapidly–rotating core galaxy IC 1459 have been presented elsewhere (Forbes, Franx & Illingworth 1994). We found IC 1459 to show only weak evidence for a photometric disk. Detection of the disk was complicated by the presence of a small–scale dust lane. The images also revealed a bright unresolved, nuclear source. Here we present WFPC1 observations for the remaining six galaxies in our initial program and complement this with similar data from *HST*. With these data, we examine the surface brightness profiles, isophotal parameters and distribution of dust for several kinematically–distinct core galaxies, and compare these properties with galaxies in the literature.

2. Observations and Data Reduction

The new PC observations presented in this paper are summarized in Table 1, along with two other kinematically–distinct core galaxies that have been presented elsewhere, i.e. NGC 4365 (Forbes 1994) and IC 1459 (Forbes, Franx & Illingworth 1994). Each pair of observations was acquired in 'fine lock' tracking mode (except for NGC 4365), with the galaxy near the center of the default CCD (PC6). The CCD chip is 800 × 800 pixels with a scale of $0.044''$/pix. The filter used was F555W ('V').

Initial data reduction was performed using the standard STScI pipeline software which follows the method outlined by Lauer (1989). We estimated the sky value ($\sim 5 \times 10^{-3}$ counts/sec) in the other PC chips far from the galaxy nucleus. This corresponds to a sky background similar to that estimated for HST images by Windhorst, Mathis & Keel (1992). This sky value was subtracted from each image, although it is small compared to the galaxy surface brightness. Each of the pair of images were compared and found to have the same central pixel value within Poisson statistics. Using the STSDAS task *imcombine*, the two images were averaged and cosmic rays removed using 3σ clipping in combination with a noise model appropriate for the PC. We carefully inspected the resulting pixel list to ensure that no pixels near the core were affected by this procedure. Two bad columns were interpolated over using the neighboring pixels. We did not apply 'delta flats' as they did not appear to remove the 'measles' (see Faber *et al.* 1992) on PC6, and quantum efficiency reduction for the date of our observations was small (less than a few percent).

Measles were removed by replacing them with values similar to the underlying galaxy at that radius.

The photometric zeropoint for PC6 derived from the Science Verification report (Faber *et al.* 1992) is $C_{F555W} = 23.08$. This is converted to Johnson V using the transformation from Harris *et al.* (1991) including a B–V color term appropriate for each galaxy (Roberts *et al.* 1991).

3. Deconvolution and Model Fitting

In order to recover structural information from WFPC1 images it is necessary to deconvolve the effects of the HST PSF. We deconvolved each galaxy using 80 iterations of the STSDAS task *lucy* with a PSF generated by *Tinytim* (Krist 1992). The PSF was simulated for the appropriate color (see Table 1), chip position (near the center of PC6), filter (F555W) and jitter (5mas). A *Tinytim* generated PSF gave similar results to those using a high S/N stellar PSF in the analysis of IC 1459 images (Forbes, Franx & Illingworth 1994).

Prior to deconvolution, many of the original galaxy images suggested the presence of dust. This is confirmed in the deconvolved images. Modeling galaxies with extensive dust can be problematic and until multi–color data are available from WFPC2 this will remain a source of uncertainty in the modeling procedure. Our method is to model the galaxy in an iterative way using *galphot* (Jørgensen, Franx & Kjaergaard 1992) which fits isophotes to the image. Our initial fit allows the position and shape parameters (ellipticity and position angle) to vary freely throughout the galaxy. By examining the input deconvolved image, the residual map (deconvolved image minus galaxy model) and the shape parameters, we determine a 'dust radius' i.e., the radius interior to which dust severly affects the galaxy starlight, thus making the model unreliable. Beyond this radius the galaxy model provides a good fit to the data. Next we determine the position and shape parameters just beyond the dust radius and use these to fix the model inputs interior to the dust radius (at larger radii they are allowed to vary). In the case of NGC 4589, there is extensive dust throughout the galaxy and so we choose the region least affected and fixed the values for the whole galaxy image. The fit is repeated giving a second residual map. From this map we define a dust mask by identifying all those pixels strongly affected by dust. For NGC 5982 no obvious dust is present and so a dust mask was not required. The fit is repeated once more, with parameters fixed interior to the dust radius, and pixels affected by dust excluded from the model. This ensures that the resulting azimuthally–averaged intensity profile is a good representation of the underlying galaxy starlight. Thus we now have a best fit model of the galaxy which gives the surface brightness and isophotal parameters as a function of radius. Subtraction of this model from the galaxy image gives the final residual map which better reveals any dust or other subtle features present. The data for NGC 4365 and IC 1459 have been reduced and deconvolved in a manner similar to that described above.

4. Results

4.1. The Galaxy Images

As mentioned earlier, many of the galaxy images (both original and deconvolved) clearly show dust with a variety of morphologies. Figure 1 (Plate **) shows a montage of the individual galaxies after deconvolution. The corresponding residual maps (after subtracting the best fit model from the deconvolved image) are shown in Fig. 2 (Plate **). This montage better displays the dust present. Six of the eight galaxies show clear evidence for dust, the exception being NGC 4365 and NGC 5982. Dust rings along the major axis are visible in NGC 1439 and NGC 4494. Small scale dust lanes and patches are seen in NGC 1427, NGC 7626 and IC 1459. NGC 4589 reveals a chaotic dust distribution extending along the minor axis and on the west side of the nucleus. Other than NGC 4589, the dust is typically found in the central $1''$. None of the galaxies, except IC 1459, show clear evidence for a central, unresolved source. Properties of the individual galaxies are summarized in Table 2 and discussed in Appendix A.

4.2. Isophotal Parameters

The isophotal parameters derived from the model fitting (section 3) are presented in Fig. 3, along with the surface brightness profile and logarithmic intensity gradient. The 3rd and 4th order, sine and cosine terms indicate deviations from a pure ellipse as described in terms of a Fourier expansion (see for example Jørgensen, Franx & Kjaergaard 1992). In particular the 4th cosine term, in conjunction with the other harmonic components, may be either positive (suggesting a disk structure) or negative (due to boxy isophotes). The derived data for the individual galaxies are listed in Appendix B.

We have examined the isophotal profiles for indications of a small scale disk, such as that possibly expected from the existence of a cold stellar component. Disks are generally hard to detect when seen at small inclinations (i.e. near face–on). At larger inclinations, one expects to see evidence for the disk, such as an increase in ellipticity and 4th cosine term. For the six new galaxies presented here, we find none very show strong evidence for any disk component interior to $10''$. There is some evidence (4th cosine at the 1.5% level) for a disk in NGC 1427 and in NGC 1439. Any disk, at small radii, in the other galaxies must contribute less than $\sim 3\%$ to the 4th cosine term. Forbes (1994) found a signature for a disk in NGC 4365 at the same radius as the maximum velocity inferred from the spectroscopic line analysis. A disk was also suggested for IC 1459 (Forbes, Franx & Illingworth 1994), but the photometric evidence was less compelling. Several galaxies have elongated isophotes at small radii.

4.3. Surface Brightness Profile

The surface brightness profiles for the galaxies in our sample show a variety of forms; several profiles rise continously towards the nucleus with little indication of flattening out (e.g. NGC 1427, NGC 1439 and NGC 4494), while others reveal a slope in the inner regions considerably less steep than further out (e.g. NGC 4365, NGC 5982, NGC 7626). The latter profiles are reminiscent of a 'broken power law' or 'dual–slope' shape, which varies from galaxy to galaxy. Although as discussed below, even these profiles are not perfect dual power laws. For IC 1459 (Forbes, Franx & Illingworth 1994) and NGC 4365 (Forbes 1994) the underlying starlight was fit with a form that contains an inner power law ($I(r) \propto r^{\alpha}$) and at large radii a fixed slope of $I(r) \propto r^{-1}$. This worked well for both galaxies. However, the surface brightness profiles for other kinematically–distinct core galaxies show a variety of forms that are not particularly well fit by the Forbes, Franx & Illingworth formulation. Thus we choose to modify the form to include a variable outer slope (β). We have also dropped the inclusion of a core radius. Only one galaxy (NGC 7626) shows possible evidence for an isothermal, or flat, surface brightness profile at the center. In this case the affects of dust at small radii may not have been fully removed. The other galaxies in our sample would require a core radius of less than one pixel in order to obtain a better fit than the dual–slope profile. We also note that deconvolution does not restore all of the light interior to $0.1''$ making the surface brightness profile an underestimate. We conclude, given the current spatial resolution, that none of the galaxies in our sample (with the possible exception of NGC 7626) have clearly isothermal cores.

We fit each surface brightness profile with the form:

$$I(r) = I_o r^{\alpha} / \sqrt{1 + (r/r_i)^{2\beta}}$$

Where r_i the inflection radius at which the slope changes from α to β. Each galaxy profile is fit between an inner radius ($= \sqrt{ab}$) of $0.1''$ and $10''$ with equal weighting (except for NGC 4494, in which the outer profile was given more relative weight as the inner profile is irregular). Interior to $0.1''$ the profile is unreliable because the deconvolution process does not restore the profile adequately (Lauer *et al.* 1992a). Both NGC 4365 and IC 1459 have been re–fit with the new formulation over the same range in radii. Figure 4 shows the galaxy surface brightness profiles with the dual power law fit superposed. The results from fits to the profiles are summarized in Table 2.

4.4. Density Profiles

We have derived density profiles from the observed surface brightness profiles, under the assumption that the galaxy is spherical (e.g. Binney & Tremaine 1987). This straightforward procedure tends to amplify the noise, because one takes the derivative of the surface brightness profile. We have proceeded in a slightly different manner by expressing the surface brightness as the sum of several Gaussians. The weights were determined using the technique of Lucy (1974). The resulting density profile, calculated directly from the fit, is then smooth.

In Fig. 5a we reproduce the surface brightness profiles for our sample galaxies overlaid on each other as a function of radius in parsecs. We also show M31, M32 and M87 (from Lauer *et al.* 1993, 1992a,b). The central point source from M87 has been removed. The corresponding luminosity density profiles, in the V band, are shown in Fig. 5b. The density profiles of our sample galaxies continue to rise steeply, reaching typical values of 10 $L_{\odot}$ pc^{-3} at a radius of 50pc from the nucleus. This is higher than M31, M32 and M87.

5. Discussion

Our sample consists of eight galaxies with well–established kinematically–distinct cores from ground–based spectroscopy. They can all be classified as either large or giant ellipticals and are located in a variety of environments. Data from the literature for these galaxies are summarized in Table 3.

Perhaps the most obvious feature of the galaxies in our sample is the presence of dust. We have found dust in at least six galaxies out of eight. In most cases this dust appears to be confined to small angular scales (i.e. $\leq 1''$), and as such is very difficult to identify in ground–based images. Indeed, for NGC 1427 (Sadler & Gerhard 1985), NGC 1439 and NGC 7626 (Lauer 1985) no dust was noted in ground–based images. Radio emission has been detected in 4 galaxies (NGC 4494, NGC 4589, NGC 7626 and IC 1459) out of 8 (Roberts *et al.* 1991). In all four cases we observe strong dust at the nucleus. For NGC 4589 and IC 1459, the dust is clearly chaotic suggesting it has yet to reach an equilibrium configuration. Kormendy *et al.* (1994) has examined a large number of elliptical galaxies with the PC and even though they were selected against the presence of known dust, they found dust at small radii to be a common feature, as we do. Given the short dynamical timescales in the central regions of these galaxies ($\sim 10^6$ yrs) it is likely that the circumnuclear dust (and gas) provides a continuing source of fuel for the radio nucleus.

For each galaxy surface brightness profile we have fit a dual–slope power law between $0.1''$ and $10''$, with an inflection radius at the change of slope. The results listed in Table 2 show that the galaxies have a range in inner slopes from almost flat to rising with $I(r) \propto r^{-0.83}$. We find no direct connection between the size of the inner region, as given by the inflection radius, and the kinematic core properties derived from ground–based spectroscopy. The physical size of the inner region for our sample galaxies seems to be concentrated around 100 pc for most galaxies. In section 5.2 we show that this is largely due to the small absolute magnitude range of our sample. We note that four galaxies (NGC 1427, NGC 1439, NGC 4494 and NGC 4589) have outer slopes of similar steepness to the inner regions making the inflection radius derived less meaningful in these cases. Futhermore, examination of the logarithmic intensity gradient in Fig. 3 shows that defining a 'unique' inflection radius may not be valid. Most galaxies show several regions of rapidly and slowly rising intensity, including the larger radii sampled by ground–based data (open triangles).

The density profiles show that the galaxies have a similar density gradient at large radii and a variety of forms at small radii. The central luminosity densities can be very high (i.e. greater than 10^3 $L_\odot$ pc^{-3}). For reasonable stellar mass–to-light ratios this suggests central mass densities as high as 10^4 $M_\odot$ pc^{-3}. These density profiles lie above, by about a factor of three, that of the compact, elliptical M32.

The high densities of the galaxies suggest that they might be quite effective in disrupting small, infalling galaxies. We have estimated the typical tidal radius of M32 when it falls into these galaxies. We assumed that the victim galaxy is on a circular orbit, and used equation 7-81 from Binney & Tremaine to evaluate the tidal radius. We find that the galaxies with steep density profiles are very effective in disrupting M32; close to the nucleus of the host galaxy, the typical tidal radius is 10 pc. On the other hand, the galaxies with the shallower density profiles (which are generally the more luminous ones) produce tidal radii of the order of 50–100 pc, and only half the mass of M32 is lost. The enclosed mass within 100 pc is still dominated by the host galaxy.

These results can be compared to the simulations by Balcells & Quinn (1990), who produced counter–rotating cores by the infall of a small galaxy into a large galaxy. The densities of their victim galaxies at 100 pc were 20–60 times larger than the density of their host galaxy. The current data suggest that such victim galaxies would be very atypical. Simulations of merging galaxies with realistic density profiles would be valuable. If one wishes to form counter–rotating cores this way, one would probably need galaxies more luminous than M32 with steep power law density profiles like NGC 1427 or NGC 1439 to fall into more luminous galaxies with shallow profiles. The end result is probably a galaxy with a steep profile, and it therefore unlikely that the galaxies with shallow profiles formed this way. This problem can possibly be circumvented by adding a massive black hole to the host galaxy. The galaxy might be able to disrupt the victim galaxy, resulting in a density profile more like that which is seen. This however, is quite uncertain and needs detailed modeling to verify.

Spectroscopic line analysis of several kinematically–distinct core galaxies has suggested that the core contains a component that is flattened and kinematically cold, i.e. a disk (Franx & Illingworth 1988; Surma 1992). One of the aims of this HST study is to look for corresponding photometric evidence for a disk. This aspect is clearly made more difficult by the ubiquitous presence of dust. Nevertheless, examination of the isophotal parameters (such as the 4th cosine term or ellipticity) can be a useful diagnostic for the presence of an underlying disk. In general, with the exception of NGC 4365, we find that there is no clear evidence for a photometric disk component corresponding to the distinct kinematic component inferred from the spectroscopic observations. We note that the ellipticity for most galaxies rises at small radii, although this could be caused by dust, it is consistent with a disk structure being present. The ability to detect a disk will be much improved with the multi–color, high Strehl ratio data available from WFPC2.

5.1. Additional Galaxies

In a magnitude–limited sample of early type Virgo galaxies, Jaffe *et al.* (1994) recently presented PC observations of two kinematically–distinct core ellipticals – NGC 4365 (previously published by Forbes 1994) and NGC 4472 (originally observed as part of HST program # 3229). NGC 4365 is included in this study (see Appendix A for a summary).

The modeled data for NGC 4365, such as surface brightness profile and isophotal parameters, presented by Jaffe *et al.* (1994) and companion papers (van den Bosch *et al.* 1994; Ferrarese *et al.* 1994) show very good agreement with that of Forbes (1994). However, the conclusions drawn from the data are somewhat different. Although, the images show no indication of dust, Jaffe *et al.* state that in NGC 4365 "...the dust is very smoothly distributed...". This statement appears to have been made on the basis of a 100μm detection by *IRAS*. Forbes (1994) found no evidence for dust in the central regions and noted that the dust mass inferred from the *IRAS* 100μm flux, when scaled by galaxy luminosity, was very low compared to a large sample of elliptical galaxies. Surma (1992) also concluded that dust was largely absent from the central regions based on B–R color information. Examining the isophotal parameters, van den Bosch *et al.* (1994) noted a "small positive cos 4θ bump around 2–3$''$" but little change in the ellipticity or position angle at this radius. They concluded there was "no evidence for a decoupled core from the photometry solely". Forbes (1994) noted a similar 4th cosine feature (see also Fig. 3), which occurs at the same location as a velocity maximum in the kinematically–distinct component (Surma 1992), and concluded there *was* "photometric evidence for a weak disk".

For NGC 4472, van den Bosch *et al.* (1994) found a very regular isophotal structure with no evidence of a photometrically distinct core. The surface brightness profile shows a shape similar to the other galaxies in our sample with an inflection at about 2$''$. Jaffe *et al.* (1994) noted that a faint radial dust feature is present near the nucleus. Strong radio emission has been detected from this galaxy by Kotanyi (1980). Thus the features of NGC 4472 are not remarkable compared to other kinematically–distinct core galaxies.

5.2. Correlations

Although the surface brightness profiles, for some galaxies in our sample, suggest a dual power law separated at the inflection radius, there does not appear to be any obvious connection to the kinematically–distinct component. As we have noted in section 5, the surface brightness profile slope may change several times with radius giving a different 'inflection radius' depending on which spatial region of the galaxy is being examined. Thus in order to compare our sample galaxies with 'kinematically–normal' galaxies, we require similar spatial scales. Initial results from a large sample of Planetary Camera F555W data have been presented by Kormendy *et al.* (1994). They suggest that the surface brightness profiles of their galaxies show a dual–slope. This is fit with two power laws which govern the inner (γ) and outer (β) slopes respectively, i.e.

$$I(r) = I_b \; 2^{\frac{\gamma-\beta}{\alpha}} \; (r/r_b)^{\gamma} \; [1 + (r/r_b)^{\alpha}]^{\frac{\beta-\gamma}{\alpha}}$$

It also contains a parameter α which controls the sharpness of the break (r_b), or inflection, between these two slopes (see Lauer *et al.* 1995 for details). For direct comparison purposes, we have re–fit our galaxy surface brightness profiles using their formulation.

We have reproduced two figures from Kormendy *et al.* (1994) which show the inner slope and the break radius at which the two power laws change. We also examined the relationship between the outer profile slope for our eight galaxies (no equivalent figure was available in Kormendy *et al.*) and find no obvious correlation with absolute magnitude. Fig. 6 shows the inner slope (γ) vs absolute V magnitude for the resolved galaxies in the Kormendy *et al.* sample, after converting the magnitudes using H_o = 50 km s^{-1} Mpc^{-1}. As noted by Kormendy *et al.* (1994), there is a trend, with considerable scatter, for the inner slope to flatten with increasing galaxy luminosity. The kinematically–distinct core galaxies in our sample are also shown, and appear consistent with the general trend. Similarly, a plot of break radius (r_b) in parsecs vs M_V shows that kinematically–distinct core galaxies are not peculiar is this regard (Fig. 7). Profile fits to the two kinematically–distinct core galaxies in the Kormendy *et al.* (1994) sample also fall within the range of parameters in both plots (Grillmair 1994). Thus we conclude that there is no obvious difference, in the surface brightness profiles, between galaxies with kinematically–distinct cores and those without. If kinematically–distinct core galaxies formed by the capture of a small compact galaxy, we would expect the surface brightness profile in the inner region to be dominated by the captured galaxy. This would suggest that the fitting parameters should lie outside of the regime for other galaxies of the same luminosity. This is not seen in our data, and so we conclude that the 'core-within-a-core' scenario for our sample galaxies is less likely.

6. Conclusions

Even before image deconvolution, our planetary camera images of several kinematically–distinct core ellipticals reveal small–scale dust to be a common feature. The distribution of this dust varies from being chaotic and patchy, to organised in a dust ring or dust lane. The short dynamical timescales in the nuclear region of these galaxies suggests that the dust (and gas) provides a source of fuel for the radio activity commonly observed in kinematically–distinct core galaxies. We have modeled each galaxy with elliptical isophotes. Even though this modeling procedure included a pixel mask which mapped the dust distribution, some distortion of the isophotes due to dust remains. This complicates interpretation of the isophotal parameters and surface brightness profiles.

The surface brightness profiles rise steeply towards the nucleus, some are fairly continous, while others flatten off but none can be described as isothermal, with the possible exception of NGC 7626. We have fit these profiles with a dual power law and an inflection radius at the location of the change of slope. Since only about half of our galaxies show a clear inflection radius, this phenomenon is not uniquely related to the presence of a kinematically–distinct core. For the galaxies with clear inflections, the scale of the inflection is similar to that of the kinematic component, but there is not a one-to-one correspondence. We find that the radius at the change of slope and inner slope power law index are correlated with absolute magnitude in the same sense as 'kinematically–normal' galaxies, namely more luminous galaxies have more extended inner regions with flatter profiles. This is not expected if kinematically–distinct core ellipticals have swallowed small, compact galaxies and if they dominate the light at small radii (typically 100 pc or less). On the other hand, if the massive galaxies contain massive black holes, then they might be able to disrupt the victim galaxies, and produce the flatter profiles that we see.

We have derived density profiles for the sample galaxies and find them to rise steeply towards the nucleus, reaching typical values of 10 $L_\odot$ pc^{-3} at 50pc. The densities are about three times higher than that of the compact elliptical M32. The galaxies with steep power law profiles are quite effective in disrupting a galaxy like M32. The galaxies with shallower profiles are not as effective, unless they contain a massive black hole.

We have searched for a small–scale photometric disk component, suggested by previous spectroscopic line analyses of several kinematically–distinct core galaxies. We find only one galaxy in our sample to show convincing photometric evidence for a disk (NGC 4365, as previously reported by Forbes 1994). For the other galaxies evidence is either marginal or not supported by our data, although the clear detection of such disks is made very difficult by the presence of dust. Better constraints will be placed when multi–color imaging is available. The ubiquitous presence of dust at small radii demonstrates that gas can also find its way to the cores of these galaxies. This also suggest that it may be easy to form kinematically–distinct stellar components from such gas, although the origin of this gas is still uncertain.

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7. Appendix A: Individual Galaxy Notes

NGC 1427 This is the least luminous galaxy in our sample. Kinematics for this galaxy are presented by Franx & Illingworth (1995). Careful study of the PC images reveal that the central structure is elongated along the minor axis i.e. a 90^o position angle shift from the outer isophotes. This appears to be the result of dust lying either side of the nucleus, although we can not rule out the possibility that the position angle shift is real and reflects a change in the underlying light distribution, e.g. a nuclear bar. There are also hints of some dust patches, located about $0.7''$ from the nucleus along the minor axis. We also note that the 4th cosine is moderately disky (1.5% level) for a radii between 1 and $2''$.

NGC 1439 This galaxy is located in the Eridanus group, along with NGC 1395 (another possible kinematically–distinct core galaxy). The peculiar kinematics were noted by Franx *et al.* (1989). The residual map clearly reveals a dust lane or ring, $\sim 1''$ (150 pc) in extent along the major axis. This gives rise to the strongly rising ellipticity interior to $1''$. The inner slope of the surface brightness profile is the steepest in our sample. There is weak evidence for a disk at radii between 4 and $10''$.

NGC 4365 This Virgo galaxy reveals a complex kinematic structure with a counter–rotating core (Bender 1988; Surma 1992). There is evidence for a small–scale disk from both spectroscopic line analysis (Surma 1992) and PC imaging (Forbes 1994; see also Jaffe *et al.* 1994). This disk can be seen as a postive 4th cosine term in Fig. 3 between 1 and $3''$. Compared to the other galaxies described here, it is interesting that NGC 4365 shows no evidence for dust and has a remarkably flat core ($\alpha = -0.17$) for a relatively faint galaxy ($M_B = -20.88$).

NGC 4494 The peculiar kinematics of this galaxy have been studied by Bender (1988) and Jedrzejewski & Schechter (1988). It is located in the Coma I cloud. A dust ring, similar in physical size (160 pc) to that seen in NGC 1439 is visible along the major axis. This dust ring causes the increased ellipticity around $2''$ radius. This radius also corresponds to the maximum velocity of the kinematically–distinct core. Goudfrooij *et al.* (1994) report minor axis dust out to $\sim 7''$ is also present. The surface brightness profile is somewhat irregular in the inner parts suggesting that the affects of dust have not yet been fully removed.

NGC 4589 Mollenhoff & Bender (1989) have studied this galaxy in some detail. They note the extensive minor axis dust which appears to be fairly symmetric on large scales. Spectroscopy reveals a complex kinematic structure with several 'humps' in the rotation curve, and suggests that the dust is in a rapidly rotating disk. Emission–line gas is observed over the central $40''$. They speculate that a gas–rich galaxy fell into NGC 4589 on "an inclined orbit near the minor axis". Our PC image confirms the presence of dust along the minor axis and also shows large dust patches to the west of the nucleus. Some of this material may fuel the compact radio nucleus (Wrobel 1991).

NGC 5982 This galaxy is paired with NGC 5985 and reveals extensive shells (Carter 1992). Peculiar kinematics were originally noted by Wagner, Bender & Mollenhoff (1988). However this galaxy may represent an example in which the inferred distinct core is not real, but rather due to projection effects in a dynamically smooth triaxial galaxy (Oosterloo, Balcells & Carter 1994; Statler 1991). We find no obvious evidence for dust in the central regions. However interior to $2''$ the ellipticity drops off dramatically, with the central isophotes becoming much more circular. This could be due to a very small central bar. Interior to $0.6''$ mottling from deconvolution prevents a stable solution.

NGC 7626 This galaxy is a giant elliptical (the most luminous in our sample), paired with NGC 7619 in a loose group. A large shell is seen in the outer eastern envelope (Jedrzejewski & Schechter 1988), and several others are revealed after model subtraction along the NE–SW direction (Forbes & Thomson 1992). This is the same direction as the observed radio jets (Jenkins 1982). The galaxy nucleus is red, hinting at the existence of dust (Sparks *et al.* 1985). A kinematically–distinct core was first discovered in this galaxy by Jedrzejewski & Schechter (1988). Recently, Balcells & Carter (1994) have mapped the central velocity field at high resolution in several position angles. They find an extremely complex kinematic structure, with several kinematically–distinct components. They conclude that the core kinematics were formed about 10^7 yrs ago and have not yet dynamically relaxed. Thus the core region is dynamically young and offers an unique opportunity to investigate a galaxy core that is still forming. We find that the central regions reveal a strong major axis dust lane extending at least $0.9''$ (300 pc) and some evidence for a minor axis dust lane as well, giving the central galaxy an '*X*' pattern. This causes the large position angle twist with respect to the outer parts of the galaxy. The radio jet lies roughly at 45^o to the dust lanes.

IC 1459 This galaxy is a giant elliptical in a loose group with several spiral galaxies. It reveals a variety of indicators suggesting a recent merger, such as a nuclear dust lane (Sparks *et al.* 1985), ionized gas disk (Forbes, Sparks & Macchetto 1990) and shells (Forbes, Reitzel & Williger 1994). It also contains the fastest known *counter–rotating* core (Franx & Illingworth 1988). Planetary camera imaging of the nuclear region has been presented elsewhere by Forbes, Franx & Illingworth (1994). We found a bright (V $\sim 18.3^m$) point source at the galaxy nucleus; making it the only galaxy in our sample to show such an obvious feature. Photometric evidence for a disk, associated with the distinct core, was ambiguous (see also Fig. 3). An irregular dust distribution was seen near the nucleus, which may indicate ongoing infall of material. The nucleus reveals a powerful compact radio core (Sadler, Jenkins & Kotanyi 1989) which appears to be variable with time (Slee *et al.* 1994).

8. Appendix B: Individual Galaxy Data

References

Balcells, M., & Quinn, P. J. 1990, ApJ, 361, 381

Bender, R. 1988, A & A, 202, L5

Bender, R. 1990, Dynamics and Interactions of Galaxies, p. 232, ed. R. Wielen, Springer-Verlag, Berlin

Bender, R., & Surma, P. 1992, A & A, 258, 250

Binney, J., & Tremaine, S. 1987, Galactic Dynamics, Princeton University Press, Princeton

Carter, D. 1992, personal communication

Crane, P., *et al.* 1993, AJ, 106, 1371

Faber, S. M., *et al.* 1992, Final Orbital/Science Verification Report, STScI

Ferrarese, L. v. d. Bosch, F. C., Ford, H. C., Jaffe, W., & O'Connell, R. W. 1994, AJ, 108, 1598

Forbes, D. A. 1994, AJ, 107, 2017

Forbes, D. A., & Thomson, R. C. 1992, MNRAS, 254, 723

Forbes, D. A., Reitzel, D. B., & Williger, G. M. 1994, AJ, in press

Forbes, D. A., Franx, M., & Illingworth, G. D. 1994, ApJL, 428, L49

Forbes, D. A., Sparks, W. B., & Macchetto, F. D. 1990, Paired and Interacting Galaxies, p. 431, ed. J. W. Sulentic, W. C. Keel and C. M. Telesco, NASA conference publication 3098

Franx, M., & Illingworth, G. D. 1988, ApJ, 327, L55

Franx, M., & Illingworth, G. D. 1995, in preparation

Franx, M., & Illingworth, G. D., Heckman, T. M. 1989, ApJ, 344, 613

Goudfrooij, P., Norgaard Nielson, H. U., Hansen, L., Jorgensen, H. E., & de Jong, T. 1990, A & A, 228, L9

Goudfrooij, P., Hansen, L., Jorgensen, H. E., & Norgaard Nielson, H. U. 1994, A & AS, 105, 341

Grillmair, C. 1994, personal communication

Harris, H. C., Baum, W. A., Hunter, D. A., & Kreidel, T. J. 1991, AJ, 101, 677

Hau, G. K. T., & Thomson, R. C. 1994, MNRAS, 270, L23

Hernquist, L., & Barnes, J. E. 1991, Nature, 354, 210

Illingworth, G. D., & Franx, M. 1989, Dynamics of Dense Stellar Systems, p. 13, ed. D. Merritt, Cambridge University Press, Cambridge

Jaffe, W., Ford, H. C., O'Connell, R. W., v. d. Bosch, F. C., & Ferrarese, L. 1994, AJ, 108, 1567

Jedrzejewski, R., & Schechter, P. L. 1988, ApJ, 330, L87

Jenkins, C. R. 1982, MNRAS, 200, 705

Jørgensen, I., Franx, M., & Kjaergaard, P. 1992, AAS, 95, 489

Kormendy, J. 1984, ApJ, 287, 577

Kormendy, J., Dressler, A., Byun, Y., Faber, S. M., Grillmair, C., Lauer, T., Richstone, D., & Tremaine, S. 1994, ESO Workshop on Dwarf Galaxies, ed. G. Meylan, Garching, ESO, in press

Kotanyi, C. G. 1980, A & AS, 41, 421

Krist, J. 1992, *Tinytim v2.1 User's Manual*, STScI

Lauer, T. R. 1985, ApJS, 57, 473

Lauer, T. R. 1989, PASP, 101, 445

Lauer, T. R., *et al.* 1991, Ap J, 369, L41

Lauer, T. R., *et al.* 1992a, AJ, 104, 552

Lauer, T. R., *et al.* 1992b, AJ, 103, 703

Lauer, T. R., *et al.* 1993, AJ, 106, 1436

Lauer, T. R., *et al.* 1995, in preparation

Lucy, L. B. 1974, AJ, 79, 745

Mollenhoff, C., & Bender, R., 1989, A & A, 214, 61

Oosterloo, T., Balcells, M., & Carter, D. 1994, MNRAS, 266, 10P

Roberts, M. S., Hogg, D. E., Bregman, J. N., Forman, W. R., & Jones, C. 1991, ApJS, 75, 751

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

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

Schweizer, F. 1990, Dynamics and Interactions of Galaxies, p. 60, ed. R. Wielen, Springer-Verlag, Berlin

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

Sparks, W. B, Wall, J. V., Thorne, D. J., Jorden, P. R., van Breda, I. G., Rudd, P. J., & Jorgensen, H. E. 1985, MNRAS, 217, 87

Statler, T. S. 1991, ApJ, 382, L11

Surma, P. 1992, Structure, Dynamics and Chemical Evolution of Elliptical Galaxies, ed. I. J. Danziger, W. W. Zeilinger and K. Kjar, ESO: Garching, p. 669

v. d. Bosch, F. C., Ferrarese, L., Jaffe, W., Ford, H. C., & O'Connell. R. W. 1994, AJ, 108, 1579

Wagner, S. J., Bender, R., & Mollenhoff, C. 1988, A & A, 195, L5

Weil, M. L., & Hernquist, L. 1993, ApJ, 405, 142

Windhorst, R., Mathis, D. F., & Keel, W. C. 1992, ApJ, 400, L1

Wrobel, J. M. 1991, AJ, 101, 127

Figure Captions

Figure 1 (Plate **) Montage of the deconvolved galaxy images. Each galaxy image has been scaled by its effective exposure time and is displayed in the log. Each horizontal bar represents 100 pc at the distance of the galaxy (H_o = 50 km s^{-1} Mpc^{-1}). The angle between the image orientation and the standard astronomical N–E axis is given by V3 (listed for each galaxy in Table 1).

Figure 2 (Plate **) Montage of the galaxy residual maps (deconvolved image minus galaxy model). A linear display is used. Each horizontal bar represents 100 pc at the distance of the galaxy. The angle between the image orientation and the standard astronomical N–E axis is given by V3 (listed for each galaxy in Table 1).

Figure 3 Galaxy parameters after deconvolution. For each galaxy, our data are shown by filled squares. The triangles respresent ground–based data (taken from Bender, Dobereiner & Mollenhoff 1988; Peletier *et al.* 1990; Djorgovski 1985). The left side, top to bottom is: surface brightness profile, logarithmic intensity gradient, ellipticity and position angle. The right side shows the harmonic components 3rd cosine, 3rd sine, 4th cosine and 4th sine terms.

Figure 4 Surface brightness profiles after deconvolution. The galaxy surface brightness profile is given by the open circles and the best–fit dual power law, between $0.1''$ and $10''$, by the solid line. See text for details. Profiles have been shifted by arbitrary amounts for display purposes.

Figure 5 Combined surface brightness and density profiles. Our sample galaxies are given by the solid lines, the dashed lines represent M32 (steepest profile), M31 (intermediate profile) and M87 (flattest profile; after subtraction of the central point source from Lauer *et al.* (1992a, 1993, 1992b).

Figure 6 Surface brightness inner slope vs absolute V magnitude for elliptical galaxies. Elliptical galaxies observed with HST from Kormendy *et al.* (1994) are given by open circles. The 8 galaxies in our sample (filled circles) have been fit with the same dual power law formulation as that used by Kormendy *et al.* The kinematically–distinct core galaxies show the same trend as other 'kinematically–normal' elliptical galaxies.

Figure 7 Surface brightness break radius vs absolute V magnitude for elliptical galaxies. The symbols are the same as given in Fig. 6. The kinematically–distinct core galaxies again show the same trend as other 'kinematically–normal' elliptical galaxies.