Line-of-sight velocity distributions of low-luminosity elliptical galaxies

C. Halliday\textsuperscript{1,4}, Roger L. Davies\textsuperscript{1}, Harald Kuntschner\textsuperscript{1}, M. Birkinshaw\textsuperscript{2}, Ralf Bender\textsuperscript{3}, R.P. Saglia\textsuperscript{3} and Glenn Baggley\textsuperscript{1}

\textsuperscript{1}Department of Physics, University of Durham, Science Labs, South Road, Durham DH1 3LE, UK.
\textsuperscript{2}H.H. Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, UK.
\textsuperscript{3}Universitäts-Sternwarte, Scheinerstr. 1, D-81679 München, Germany.
\textsuperscript{4}Current address: Astrophysics Research Institute, Liverpool John Moores University, Twelve Quays House, Egerton Wharf, Birkenhead CH41 1LD, UK. email: ch@astro.livjm.ac.uk

Accepted — 2001. Received — ; in original form —

ABSTRACT
The shape of the line-of-sight velocity distribution (LOSVD) is measured for a sample of 14 elliptical galaxies, predominantly low-luminosity ellipticals. The sample is dominated by galaxies in the Virgo cluster but also contains ellipticals in nearby groups and low density environments. The parameterization of the LOSVD due to Gerhard and van der Marel & Franx is adopted, which measures the asymmetrical and symmetrical deviations of the LOSVD from a Gaussian by the amplitudes $h_3$ and $h_4$ of the Gauss-Hermite series. Rotation, velocity dispersion, $h_3$ and $h_4$ are determined as a function of radius for both major and minor axes. Non-Gaussian LOSVDs are found for all galaxies along the major axes. Deviations from a Gaussian LOSVD along the minor axis are of much lower amplitude if present at all. Central decreases in velocity dispersion are found for three galaxies. Two galaxies have kinematically-decoupled cores: NGC 4458 and the well-known case of NGC 3608.

Key words: galaxies: formation - galaxies: elliptical and lenticular - galaxies: kinematics and dynamics

1 INTRODUCTION
The shape and strength of absorption features provide a direct measure of the kinematics of integrated stellar populations in early-type galaxies (e.g., Sargent et al. 1977, Tonry & Davis 1979). Large format CCD arrays of small pixels enable two-dimensional studies of galaxy kinematics at high spectral and spatial resolution to be made using long-slit spectroscopy. This has led to the study of the line-of-sight velocity distribution (LOSVD) at different positions within a galaxy, allowing the kinematical structure to be tightly constrained (e.g., Franx & Illingworth 1988, hereafter FI88; Bender 1990, hereafter B90; Rix & White 1992, hereafter RW92; van der Marel & Franx 1993, hereafter vdmMF93; Bender, Saglia & Gerhard 1994, hereafter BSG94, van der Marel et al. 1994, hereafter vdm94a, Fisher et al. 1995, hereafter F95, Statler & Smecker-Hane 1999, hereafter SSH99, Mehler et al. 2000).

The orbital structure of a galaxy is a fossil record of its evolutionary history. However, there is a degeneracy between changes in mass-to-light ratio and velocity dispersion anisotropy that limits the analysis of rotation and dispersion measurements alone (Binney & Tremaine 1987). To recover the mass density distribution of a given galaxy requires at least an accurate determination of the velocity dispersion anisotropy through the LOSVD. A full determination of the galaxy dynamics would require the measurement of surface brightness profiles and is beyond the scope of this work but an accurate measurement of the LOSVD is an important step in achieving this (e.g., van der Marel et al. 1994, hereafter vdm94b; Saglia et al. 2000).

To a first approximation, elliptical galaxies are believed to be relaxed dynamical systems and the distribution of stellar velocities has been assumed to be Maxwellian producing approximately Gaussian profiles. However, within a number of ellipticals non-Gaussian LOSVDs have been measured. For example, see Figure 3 for LOSVDs measured in NGC 5582 at various radii. The non-Gaussian LOSVDs led to the detection of multiple component structures in ellipticals, such as kinematically-decoupled cores (FI88; Jedrzejewski & Schechter 1988, hereafter JS88), and central disks (RW92; van den Bosch et al. 1998). It has been demonstrated that under the assumption of Gaussian LOSVDs, the mea-
measurement of both rotation velocity and velocity dispersion can be incorrect by 10% or more (vdMF93).

To improve on the earlier measurements, more general parameterizations of the LOSVD have been tested and have been found to provide a superior description of the galaxy kinematical structure (RW92; vdMF93; Kuijken & Merrifield 1993; Zhao & Prada 1996). Here galaxy kinematics are measured using the Fourier Correlation Quotient (FCQ) method of B90. This method is considerably less sensitive to template-mismatching than traditional Fourier methods and allows the measurement of the full LOSVD. The LOSVD is then parameterized as a Gauss-Hermite series expansion (vdMF93) including the higher order terms $b_3$ and $b_4$.

The galaxy sample studied here consists mostly of low-luminosity ellipticals (hereafter LLEs). Evidence has grown steadily over the past 15 years that LLEs may be very different from the more luminous giant ellipticals, both in their kinematical behaviour (Davies et al. 1983, hereafter DEFIS83; Bender & Nieto 1990; Rix et al. 1999) and the properties of their stellar populations (e.g. Faber et al. 1992). As isotropic rotators (DEFIS83), LLEs are more easily modelled than the giant ellipticals which are believed to be supported by velocity dispersion anisotropy. Furthermore, the lower velocity dispersion broadening of LLEs enables the higher-orders of the LOSVD to be measured more accurately than for the more luminous ellipticals, provided that data of sufficiently high spectral resolution and signal-to-noise ratio (hereafter S/N) can be obtained.

The main objective of the measurements described here is to constrain the kinematical structure of our LLE sample as a function of radius. In Section 2 observations and reduction steps are described. The adopted LOSVD parameterization is presented and discussed in Section 3. A description of the measurement of galaxy kinematics using the FCQ method and measurements of rotation, $\sigma$, $b_3$ and $b_4$ are given in Section 3 and Appendix A. A short analysis of characteristic global kinematic parameters for the major axis of our sample is presented in Section 4 and a discussion of our results is given in Section 5. Comparisons between measurements obtained here and the measurements of previous authors are presented in Appendix B.

2 OBSERVATIONS AND BASIC REDUCTION

2.1 Galaxy Sample

A complete sample of 17 low-luminosity elliptical galaxies was selected from the Virgo catalog of Bingelli et al. (1985) covering the absolute magnitude range $-20 \leq M_B \leq -17$.

Nine galaxies of this original sample were observed. Other low-luminosity ellipticals (NGC 2778, NGC 3377, NGC 3605, NGC 3608, NGC 55582) were observed when Virgo was not available due to cloudy or windy conditions. The well studied ‘bona fide’ elliptical NGC 3379 was observed to enable consistency checks to be made with the measurements of other authors. Our observed sample is given in Table 1 which lists the morphological type, apparent magnitude $B_T$, the effective radius in arcsec ($R_e$), mean ellipticity, heliocentric redshift, $cz_{\text{helio}}$ and environment. Values of absolute magnitude, as listed also in Table 1, were calculated using the distances from the surface-brightness-fluctuation survey of Tonry et al. (2001). Specifically we use a mean distance of 17.0 Mpc to the Virgo cluster, 11.1 Mpc to the Leo I group and 21.8 Mpc to the Leo II group. Two galaxies, NGC 2778 and NGC 55582, are in low density environments and we use the individual SBF distances of 16.9 Mpc and 28.4 Mpc, respectively.

2.2 Description of Observations

Long-slit spectroscopic data were obtained using the Blue Channel Spectrograph at the Multiple Mirror Telescope, Arizona, U.S.A., during 5-7 March and 15-17 May 1994, and 22-26 February 1995. The seeing varied from 0.5 to 2.0 arcsec. The Loral CCD detector of the Blue Channel Spectrograph was replaced between the observing runs of May 1994 and February 1995 with a chip of improved cosmetics. A summary of the instrumental set-up is given in Table 2. A wavelength range of 4555-6045 Å was chosen to be centred on the Mg$b$, Fe5270 & Fe5335 Lick/IDS line-strength indices (Trager et al 1998). To accurately determine values of $\sigma$ of as low as 60 km s$^{-1}$, a high spectral resolution of 1.5 Å FWHM was required; for this purpose a grating of 1200 grooves/mm and a slit width of 1 arcsec were used. The resolution element in the spatial direction was re-binned by 2 pixels to produce a spatial scale of 0.6 pixel$^{-1}$. The slit length was 180 arcsecs.

High S/N long-slit spectra were obtained for the major and minor axes of each galaxy of our sample. To determine kinematics 3-8 stellar template stars, predominantly G and K giants, were observed during each night. A log of all galaxy observations is given in Table 2; this includes the
Table 1. Observed Galaxy Sample

| Name       | Type | B_T | R_e | ǫ | cz_helio | M_B | environment |
|------------|------|-----|-----|---|----------|-----|-------------|
| NGC 2778   | E    | 13.35 | 15.74 | 0.22 | 2019 | -18.5 | -           |
| NGC 3377   | E5+  | 11.24 | 34.45 | 0.48 | 692  | -19.0 | Leo I group |
| NGC 3379   | E0   | 10.24 | 35.25 | 0.09 | 889  | -20.0 | Leo I group |
| NGC 3605   | E+   | 13.13 | 21.24 | 0.34 | 649  | -18.6 | Leo II group|
| NGC 3608   | E2   | 11.70 | 33.66 | 0.21 | 1205 | -20.0 | Leo II group|
| NGC 4239   | E    | 13.70 | 15.39 | 0.46 | 921  | -17.5 | Virgo       |
| NGC 4339   | E0   | 12.26 | 32.15 | 0.08 | 1281 | -18.9 | Virgo       |
| NGC 4387   | E    | 13.01 | 15.74 | 0.35 | 561  | -18.1 | Virgo       |
| NGC 4458   | E0+  | 12.93 | 26.13 | 0.13 | 668  | -18.2 | Virgo       |
| NGC 4464   | S?   | 13.46 | 7.54  | 0.24 | 1255 | -17.7 | Virgo       |
| NGC 4467   | E2   | 14.77 | 10.64 | -   | 1474 | -16.4 | Virgo       |
| NGC 4468   | S0?  | 13.58 | 27.36 | 0.29 | 895  | -17.6 | Virgo       |
| NGC 4478   | E2   | 12.36 | 13.40 | 0.17 | 1382 | -18.8 | Virgo       |
| NGC 4551   | E    | 12.97 | 13.10 | 0.23 | 1332 | -19.1 | Virgo       |
| NGC 4564   | E6   | 12.36 | 13.40 | 0.17 | 1382 | -18.8 | Virgo       |
| NGC 4568   | S0   | 12.97 | 13.10 | 0.23 | 1332 | -19.1 | Virgo       |

Notes: Values of B_T in magnitudes, effective radius R_e in arcsec, and heliocentric redshift cz_helio in km s^{-1} were taken from the Third Reference Catalogue (de Vaucouleurs et al. 1991, hereafter RC3). The Hubble type, also taken from the RC3, is given in column 2: E-elliptical, S-spiral, S0-lenticular, +-intermediate (i.e. between elliptical and S0), ?-doubtful classification. Column 5 provides the mean ellipticity used in Section 5: these values were taken from Peletier et al. (1990), Bender et al. (1989) and Lauer et al. (1995); for NGC’s 4239, 4339, 4458, 4468, 5582 values were obtained from the Digital Sky Survey. To calculate the absolute magnitude M_B (column 7) we used the distances based on the surface-brightness-fluctuation survey of Tonry et al. (2001). Galaxies from Bingelli et al. (1985) that were contained in our original sample, but could not be observed are NGC 4168, NGC 4261, NGC 4360, NGC 4486A, NGC 4515, IC 3653, NGC 4623, NGC 4660. Column 8 indicates whether each galaxy is a member of the Virgo cluster, the Leo I group, the Leo II group or resides in a low density environment (-).

Table 2. The instrumental set-up

| Telescope | MMT |
|-----------|-----|
| Instrument| MMT spectrograph, blue channel |
| Grating | 1200 g/mm |
| Detector | Loral (3k x 1k) |
| Pixel Size | 15µm x 15µm |
| Readout Noise | \sim 7 - 8 e^- |
| Gain | \sim 1.5 e^-/ADU |
| Slit width | 1" |
| Spatial Scale | 0.6/6/pixel a |
| Instr. resolution | \sim 1.5 Å (FWHM) |
| Dispersion | 0.5 Å/pixel |
| Wavelength range | 4555 - 6045 Å |

a binned 2x minimum bin size in spatial direction

The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166.

2.3 Basic Reduction

A standard data reduction was performed principally using IRAF. To complete the measurement of galaxy kinematics additional steps were performed using IRAF and MIDAS.

Reduction steps, performed for each night of observation, are summarized; for a more detailed description see

* Image Reduction and Analysis Facility of the National Optical Astronomy Observatories, Tuscon, Arizona, U.S.A..
† Munich Image Data Analysis System of the European Southern Observatory.
Halliday (1998). All CCD observations were bias-subtracted, flat-fielded and corrected for the effects of both cosmic ray hits and bad pixel columns. A wavelength calibration was performed for each star and galaxy frame to a typical accuracy of 0.05 Å (~3 km s⁻¹ at ~5200 Å). A series of distortion maps were created to geometrically rectify each frame to a typical accuracy of 0.2 pixels RMS (~6 km s⁻¹ at ~5200 Å). Background sky signal was subtracted for each galaxy frame by linearly-interpolating between areas of sky at opposite sides of the galaxy spectrum. A correction for chromatic focus variations within a galaxy frame was made where required. This involved measuring the central width of the galaxy profile as a function of wavelength. A procedure was developed to smooth the galaxy profile width to the same value for all wavelengths. This was similar to a procedure adopted by Mehlert et al. (1998) to correct for chromatic focus variations detected within their data. The dispersion axis of each galaxy frame was finally rebinned on to a natural logarithmic scale.

A one-dimensional stellar spectrum was created for each ‘rocked’ star frame by extracting individual ‘strips’ of spectra within each frame. These were combined to produce a single one-dimensional spectrum and deredshifted to laboratory wavelengths.

### Table 3. Observing Log

| Date      | Name    | PA (deg.) | Exp. (s) |
|-----------|---------|-----------|----------|
| 05.03.94  | NGC 3605 | 290 min   | 3600     |
| 05.03.94  | NGC 3605 | 300 maj   | 3600     |
| 05.03.94  | NGC 4387 | 322 maj   | 3600     |
| 05.03.94  | NGC 4387 | 52 min    | 3600     |
| 05.03.94  | NGC 4564 | 135 min   | 3600     |
| 05.03.94  | NGC 4468 | 155 min   | 3600     |
| 06.03.94  | NGC 3608 | 351 min   | 3600     |
| 06.03.94  | NGC 2778 | 225 maj   | 3600     |
| 06.03.94  | NGC 2778 | 135 min   | 3600     |
| 06.03.94  | NGC 5582 | 205 maj   | 3600     |
| 15.05.94  | NGC 4564 | 45 maj    | 3600     |
| 15.05.94  | NGC 4468 | 65 maj    | 3600     |
| 15.05.94  | NGC 4464 | 95 min    | 3600     |
| 15.05.94  | NGC 4464 | 5 maj     | 3600     |
| 15.05.94  | NGC 5582 | 295 min   | 4200     |
| 16.05.94  | NGC 3608 | 81 maj    | 3600     |
| 22.05.95  | NGC 4467 | 41 maj    | 3600     |
| 22.05.95  | NGC 4467 | 131 min   | 3600     |
| 23.05.95  | NGC 3378 | 71 maj    | 600      |
| 23.05.95  | NGC 3379 | 161 min   | 600      |
| 23.05.95  | NGC 3377 | 42 maj    | 1800     |
| 23.05.95  | NGC 3377 | 312 maj   | 1800     |
| 23.05.95  | NGC 4551 | 70 maj    | 3600     |
| 23.05.95  | NGC 4551 | 340 min   | 3600     |
| 23.05.95  | NGC 4458 | 5 maj     | 3600     |
| 23.05.95  | NGC 4458 | 95 min    | 3600     |
| 23.05.95  | NGC 4478 | 145 maj   | 3600     |
| 24.05.95  | NGC 4478 | 55 min    | 3600     |
| 24.05.95  | NGC 4339 | 20 maj    | 2700     |
| 24.05.95  | NGC 4339 | 110 min   | 2700     |
| 24.05.95  | NGC 4239 | 115 maj   | 5400     |

**Notes:** The date of each observation and galaxy name is given in columns 1 & 2, respectively. Column 3 gives the position angle of the observation with sense North through East; positions corresponding to the major (maj) and minor (min) axes are indicated. Column 4 lists the exposure time in seconds.

Halliday (1998). All CCD observations were bias-subtracted, flat-fielded and corrected for the effects of both cosmic ray hits and bad pixel columns. A wavelength calibration was performed for each star and galaxy frame to a typical accuracy of 0.05 Å (~3 km s⁻¹ at ~5200 Å). A series of distortion maps were created to geometrically rectify each frame to a typical accuracy of 0.2 pixels RMS (~6 km s⁻¹ at ~5200 Å). Background sky signal was subtracted for each galaxy frame by linearly-interpolating between areas of sky at opposite sides of the galaxy spectrum. A correction for chromatic focus variations within a galaxy frame was made where required. This involved measuring the central width of the galaxy profile as a function of wavelength. A procedure was developed to smooth the galaxy profile width to the same value for all wavelengths. This was similar to a procedure adopted by Mehlert et al. (1998) to correct for chromatic focus variations detected within their data. The dispersion axis of each galaxy frame was finally rebinned on to a natural logarithmic scale.

A one-dimensional stellar spectrum was created for each ‘rocked’ star frame by extracting individual ‘strips’ of spectra within each frame. These were combined to produce a single one-dimensional spectrum and deredshifted to laboratory wavelengths.

### 3 PARAMETERIZATION OF THE LINE-OF-SIGHT VELOCITY DISTRIBUTION

The line-of-sight velocity profile was decomposed using the parameterization proposed by Gerhard (1993) and van der Marel and Franx (1993):

$$f(y) = I_0 e^{-\frac{y^2}{2\sigma^2}} \left(1 + h_3 f_{3y} + h_4 f_{4y}\right)$$

where $y = \frac{(v_{fit} - \nu)}{\sigma_{fit}}$, $v_{fit}$ is the measured velocity; $\nu$ is the mean of all measured velocities for a given spectrum (i.e., the mean radial velocity); $\sigma_{fit}$ is the measured velocity dispersion; $H_3(y)$ and $H_4(y)$ are antisymmetric and symmetric standard Gauss-Hermite polynomials of 3rd and 4th order and $h_3$ and $h_4$ are their coefficients, respectively; and $I_0$ is a normalization constant.

The coefficient $h_3$ quantifies the LOSVD asymmetry. Measured asymmetries for elliptical galaxies arise from a non-Gaussian velocity distribution along the line-of-sight, e.g., the superposition of a slowly rotating bulge and a more rapidly rotating disk component. Positive measurements of $h_3$ correspond to a distribution skewed towards velocities lower than the measured systemic velocity of the galaxy. Conversely negative $h_3$ measurements correspond to distributions skewed towards velocities greater than the systemic velocity.

The $h_4$ term quantifies the symmetric deviations of the LOSVD from a Gaussian. For $h_4 > 0$ the corresponding distribution is more peaked than a Gaussian at small velocities with more extended high velocity tails. Conversely, distributions less peaked than a Gaussian will have $h_4 < 0$.

### 4 GALAXY KINEMATICS: MEASUREMENT AND RESULTS

Measurements of rotation, $\sigma$, $h_3$ and $h_4$ were obtained using the FCQ method of B90. This procedure involved extraction of an appropriate wavelength range, binning the spectra as a function of radius to a particular value of S/N, continuum level removal and application of a Wiener filter.

Optimal values of parameters for each of the measurement steps were established using Monte-Carlo simulations. Simulated ‘galaxy’ spectra for particular measurements of $\sigma$, $h_3$ and $h_4$ were created from one-dimensional stellar spectra. To model the effect of noise in simulations for a given S/N, different Gaussian noise realisations were added to 30 copies of each simulated galaxy spectrum. The mean value and spread of kinematical measurements obtained for the different spectra were used to determine the optimal value for each parameter (for details see Halliday 1998).

From our overall wavelength range, we extracted a range centred on the Mg$b$ spectral feature and excluding H$\alpha$. Galaxy spectra were rebinned in the direction of the spectroscopic slit to a minimum signal-to-noise ratio (S/N) of 60 per Å and separately for S/N = 30 per Å. The shapes...
LOSVDs of low-luminosity elliptical galaxies

5 CHARACTERISTIC KINEMATIC PARAMETERS

In this section characteristic, global kinematic parameters are derived and analysed for the major axes of each galaxy. Six parameters were determined for each individual galaxy: $v_{\text{max}}$, the maximum measured rotation velocity; $\sigma_0$, $\sigma_{\text{max}}$ and $\overline{\sigma}$, the central, maximum and mean velocity dispersion, respectively. For $\overline{\sigma}$, values were taken to be the mean of all measurements within $1/2 R_e$. Furthermore $|h_3|$, the mean of the absolute values of $h_3$, and $|h_4|$, the mean value of $h_4$ were determined. For $|h_3|$, $|h_4|$ and $|h_4|$ the mean of all measurements within $1/2 R_e$, excluding the innermost measurements ($|r| \leq 2''6$), was taken. Uncertainties were calculated by propagating the errors determined for the original measurements of rotation, $\sigma$, $h_3$ and $h_4$. A summary of all values is given in Table 4.

In Figure 3(a) the ratio of $v_{\text{max}}$ to $\overline{\sigma}$ is plotted against $|h_3|$ for each galaxy. We note that there is a weak trend such that galaxies with larger ratios of $v_{\text{max}}/\overline{\sigma}$ have on average larger values of $|h_3|$. This suggests that greater rotational support may be related to larger LOSVD asymmetries. In Figure 3(b) it is shown that the largest values of $|h_3|$ are measured for galaxies with intermediate values of $\sigma_0$. LOSVD asymmetries may be more common for these galaxies. A larger sample is needed to confirm this suggestion.

6 DISCUSSION

We have demonstrated in Section 3 that for our sample of LLEs the global kinematic parameters such as $v_{\text{max}}$, $\overline{\sigma}$ and $\overline{\sigma}$ are consistent with the predictions for a simple oblate rotator model.

In general, however, we find a wide range of complex kinematical behaviour in our sample. There is a wide range of velocity dispersion gradients with radius. Some galaxies, such as NGC 3377, show a steep decline, whereas others, such as NGC 4551, have a rather shallow profile. Central decreases in $\sigma$ are measured for three galaxies for the major and minor axes (NGC 4387, NGC 4478 and NGC 4551), and two galaxies (NGC 3608 and NGC 4458) are found to have kinematically-decoupled cores (KDCs). Significant asymmetric line-of-sight velocity distributions, parameterized by the Gauss-Hermite coefficient $h_3$, are measured for 13 low-luminosity ellipticals. These asymmetries are found mainly for radii close to the galaxy centre, and suggest that we are detecting the motion of two or more components of different kinematical properties in at least some of the low-luminosity ellipticals.

The LOSVDs along the minor axis are generally consistent with a Gaussian shape. Only a few galaxies show significant $h_3$ or $h_4$ terms. In the cases where non-Gaussian LOSVDs are detected this can be explained by isophote twisting such that our slit does not follow the exact location of the kinematic minor axis. This may also explain the non-zero velocities measured for some galaxies along the minor axis (e.g., NGC 3377 and NGC 4464). NGC 4478 is the most spectacular case, since it exhibits signs of disturbed, perhaps unrelaxed kinematics. This galaxy is not axisymmetric and any dynamical model would need to be triaxial. This is also likely to be the case for the other galaxies which show non-zero velocities along the minor axis.
Some of the kinematic signatures we detect in our sample of LLEs, such as KDCs and central dips in velocity dispersion, are indicative of a merger scenario. It is interesting to note that in their recent merger simulations, Bendo and Barnes (2000, hereafter BB2000) have presented LOSVDs for the merger remnants of two spiral galaxies, which resemble elliptical galaxies. In these simulations central dips in  in were found for remnants of an *equal-mass* merger of two spirals. Predictions for the profiles of rotation,  and  are different from those observed in our study. In most cases  is predicted to have a similar sign to the rotation velocity close to the galaxy centre; for our galaxy sample,  has an *opposite* sign to rotation. In one case in the study of BB2000, where  and rotation do have opposite signs, the merger remnant has a counterrotating core: neither of the two galaxies in our sample with a counterrotating core (i.e. NGC 3608 and NGC 4458) have a central decrease in  . For NGC 4387, rotation rises steadily outside the galaxy centre in agreement with the simulation results, although  is consistent with zero in contrast to the predicted values of positive . Rotation velocities for the unequal-mass mergers considered by BB2000 are of far greater amplitude than the velocities measured in this study.

Our long-slit observations provide a valuable insight into the dynamics of LLEs and demonstrate clearly that there exists a wide range of complex, sometimes non-axisymmetric kinematics. With data available only for the major and minor axis of a galaxy it is difficult, if not impossible, to describe the full dynamical make-up of galaxies. The newly commissioned integral field units such as SAURON (Bacon et al. 2001), however, provide 2-dimensional rotational velocity and velocity dispersion maps of early-type galaxies and will advance this area of astronomy.

## 7 ACKNOWLEDGEMENTS

We thank the CFA Observing Time Committee for their generous allocation of telescope time. CH thanks Frank van den Bosch for kindly providing his photometric measurements for NGC 4478 and NGC 4564. CH acknowledges helpful discussions with Reynier Peletier and the support of a PPARC studentship at the University of Durham and a PPARC PDRA grant at Liverpool JMU. HK was supported at the University of Durham by a PPARC rolling grant in Extragalactic Astronomy and Cosmology.

### REFERENCES

Bacon, R., et al., 2001, MNRAS, submitted
Bender, R., Surma, P., Döbereiner, S., Möllenhoff, C., Madejsky, R., 1989, AA, 217, 35
Bender, R., 1990, AA, 229, 441 (B90)
Bender, R., Saglia, R. P., Gerhard, O. E., 1994, MNRAS, 269, 785 (B94)
Bendo, G. J., Barnes, J. E., 2000, MNRAS, 316, 315 (BB2000)
Binney, J., 1978, MNRAS, 183, 501
Binney, J., Tremaine, S., 1987, Galactic Dynamics, Princeton University Press
Binggeli, B., Tammann, G., Sandage, A., 1985, AJ, 90, 1681
Carollo, C. M., Franx, M., Illingworth, G. D., Forbes, D. A., 1997, ApJ, 481, 710 (C97)
Carter, D., 1987, ApJ, 312, 514
Davies, R. L., Ellis, R. S., Fall, S. M., Illingworth, G., Schechter, P. L., 1983, ApJ, 266, 41 (DEFIS83)
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G. J., Buta, R. J., Paturel, G., Fouqué, P., 1991, Third Reference Catalogue of Bright Galaxies. Springer Verlag (RC3)
Faber, S. M., Worthey, G., Gonzales, J. J., 1992, IAU Symp. 149, The Stellar Populations of Galaxies, 149, 255. Springer Verlag
Fisher, D., Franx, M., Illingworth, G., 1995, ApJ, 448, 119 (F95)
Franx, M., Illingworth, G., 1988, ApJ, 327, L55 (F88)
Gerhard, O. E., 1993, MNRAS, 265, 213

---

| Name       |  |  |  |  |  |  |  |  |  |  |  |
|------------|---|---|---|---|---|---|---|---|---|---|---|
| NGC2778    | 109.4 | 9.3 | 196.2 | 1.0 | 168.7 | 0.9 | 142.1 | 0.6 | 0.078 | 0.008 | 0.028 | 0.009 |
| NGC3377    | 100.1 | 0.9 | 156.0 | 1.8 | 156.0 | 1.8 | 101.6 | 0.5 | 0.124 | 0.006 | -0.035 | 0.009 |
| NGC3379    | 50.0 | 5.7 | 224.5 | 2.8 | 221.1 | 2.9 | 209.5 | 1.3 | 0.025 | 0.009 | -0.001 | 0.010 |
| NGC3605    | 55.9 | 8.5 | 91.9 | 0.6 | 90.8 | 0.5 | 87.6 | 0.2 | 0.042 | 0.005 | 0.002 | 0.005 |
| NGC3608    | 45.4 | 5.2 | 201.6 | 0.8 | 201.6 | 0.8 | 179.3 | 0.4 | 0.034 | 0.003 | 0.016 | 0.003 |
| NGC3439    | 56.3 | 5.4 | 115.2 | 1.0 | 115.2 | 1.0 | 100.4 | 0.5 | 0.072 | 0.007 | 0.081 | 0.010 |
| NGC4387    | 59.8 | 7.4 | 104.1 | 0.9 | 97.9 | 0.6 | 97.1 | 0.3 | 0.013 | 0.003 | 0.009 | 0.004 |
| NGC4458    | 26.3 | 1.2 | 119.0 | 2.1 | 119.0 | 2.1 | 97.8 | 0.7 | 0.059 | 0.013 | -0.035 | 0.018 |
| NGC4464    | 78.0 | 1.2 | 141.2 | 0.6 | 141.2 | 0.6 | 120.9 | 0.4 | 0.150 | 0.007 | 0.051 | 0.008 |
| NGC4468    | 24.2 | 2.9 | 36.2 | 1.6 | 34.6 | 1.2 | 33.2 | 0.8 | 0.029 | 0.043 | -0.060 | 0.027 |
| NGC4478    | 58.4 | 3.1 | 146.0 | 3.7 | 126.3 | 2.0 | 131.7 | 0.8 | 0.054 | 0.007 | -0.014 | 0.008 |
| NGC4551    | 46.6 | 2.0 | 103.5 | 1.2 | 103.5 | 1.2 | 95.2 | 0.4 | 0.053 | 0.005 | -0.034 | 0.008 |
| NGC4564    | 153.2 | 1.6 | 177.4 | 0.4 | 177.4 | 0.4 | 144.8 | 0.2 | 0.027 | 0.002 | -0.016 | 0.002 |
| NGC4558    | 165.2 | 10.0 | 164.6 | 0.7 | 164.6 | 0.7 | 125.8 | 0.5 | 0.169 | 0.007 | 0.104 | 0.010 |

Global parameters, as plotted in figures 2 and 4 are given for the major axis spectrum of each galaxy. Columns 2 & 3 give the maximum measured rotation velocity and its error. The maximum, central and mean velocity dispersion and their corresponding errors are given in columns 4 & 5, 6 & 7 and 8 & 9, respectively. Columns 10 & 11 give the mean absolute value of  and its error. The mean value of  and its error are given in columns 12 & 13. All measurements of velocity and  are given in km s$^{-1}$.
Figure 2. Comparison of measurements of $v_{\text{max}}/\sigma$ against the mean ellipticity $\epsilon$, with predictions for oblate isotropic models (Binney 1978, solid line). Measurements for galaxies studied here are indicated by filled circles. A typical error bar for $v_{\text{max}}/\sigma$ is given in the upper left-hand corner. Additional measurements are from DEFIS83: measurements for giant ellipticals are given by asterisk symbols, and low-luminosity ellipticals are represented by open triangles.
APPENDIX A: MEASUREMENTS OF GALAXY KINEMATICS

We present our measurements for $v$, $\sigma$, $h_3$, and $h_4$ as a function of radius for all galaxies in order of their NGC number.

The systemic velocity of each galaxy was removed by subtracting the mean velocity. Small shifts (<8 km s$^{-1}$) were applied in order to centre the velocity profile about the apparent kinematic centre of the galaxy. The PA of observation is indicated in each case (values of positive radius correspond to positions in the direction of the PA). Measurements of rotation, $\sigma$, $h_3$ and $h_4$ obtained for a S/N binning of $\simeq 60$ per $\AA$ are shown by asterisk and open circle symbols for values away from and in the direction of the PA, respectively. Additional measurements for rotation and $\sigma$, obtained for a lower S/N binning of $\simeq 30-35$ per $\AA$, define greater spatial detail and extend to greater radii; these are plotted as open star and open square symbols, away from and in the direction of the PA, respectively. Measurements of rotation and $h_3$ for radii away from the direction of PA are multiplied by -1 in folding. For some galaxies (NGC2778, NGC4339, NGC4464, NGC4468, NGC4478, NGC5582) the major axis rotation and $h_3$ measurements are plotted such that the rotation shows mostly positive values.

Where a chromatic focus variation correction for a particular spectrum was applied, this is indicated and the corresponding effective smoothing in arcsec is given. Considerable reference is made to photometry available in the literature, e.g., U, B, and R-band photometry of Peletier et al. (1990, hereafter P90), HST WFPC-1 V-band photometry of van den Bosch et al. (1994, hereafter vdB94) and Lauer et al. (1995, hereafter L95) and HST WFPC-2 V and I-band photometry of Carollo et al. (1997, hereafter C97).

Tables for measurements presented in this appendix are available electronically from the Centre de Donnees astronomiques de Strasbourg (CDS).

A1 NGC 2778

Classified as elliptical in RC3, rotation and velocity dispersion were measured previously for this galaxy by DEFIS83 and F95. Photometry was obtained by P90 who detected a small amount of diskiness for $r \leq 7''$, and a gradual isophotal twisting between 3'2 and 40'1, from 45'8 to 42'1.

For the major axis, $h_3$ is non-zero for $|r| < 8''$ (see Figure A1). $h_4$ is positive for $r \sim 7''$.5. For the minor axis, $h_3$ and $h_4$ are mostly consistent with zero; only at $r \sim 4''$ is a positive $h_4$ detected.

A2 NGC 3377

A member of the Leo I group, NGC 3377 is widely considered to be a “disky” elliptical. It is classified as an intermediate E5 elliptical galaxy in RC3 and E6 in Sandage and Tammann (1987, hereafter RSA). Photometric measurements by Carter (1987), P90 and Scorza & Bender (1995, hereafter SB95) have shown this galaxy to be “disky” for the range of radii studied here beyond which it becomes “boxy”.

For the major axis, $h_3$ is non-zero for almost all radii. $h_4$ is mostly consistent with zero (see Figure A2). For the minor axis, $h_3$ and $h_4$ are mainly consistent with zero. The rotation curve of the major axis is steeply rising to $\sim$110 km s$^{-1}$ within $r \leq 3''$ and stays roughly constant out to 40'''. The minor axis shows non-zero velocities for $3'' < |r| < 10'''$. Our non-zero measurements of $h_3$ along the major axis are non-zero for almost all radii. $h_4$ is mostly consistent with zero (see Figure A2). For the minor axis, $h_3$ and $h_4$ are mainly consistent with zero. The rotation curve of the major axis is steeply rising to $\sim$110 km s$^{-1}$ within $r \leq 3''$ and stays roughly constant out to 40'''. The minor axis shows non-zero velocities for $3'' < |r| < 10'''$. Our non-zero measurements of $h_3$ along the major axis are

© 2001 RAS, MNRAS 000, 000–000
Figure A1. Major and minor axis observations for NGC 2778 (PA 225° and 135°, respectively). Focus corrections were applied for both spectra corresponding to a maximum Gaussian smoothing of 0.81 and 1.08, respectively. The seeing for these observations was approximately 1″. The effective seeing, after chromatic focus corrections, is 1″29 and 1″47, respectively. Data points cannot be assumed to be independent at this level. In all figures, measurements obtained for a S/N ≃ 60 per Å are presented by asterisk and open circle symbols for values away from the direction of, and in the direction of the PA, respectively. Additional measurements for rotation and \(\sigma\), obtained for a lower S/N ≃ 30-35 per Å, are plotted as open star and open square symbols, away from and in the direction of the PA, respectively.

NGC 3377 is a member of the Leo-I group and is a well observed elliptical, classified as E1 in RC3.

For the major axis, rotation decreases at \(r \approx 4″\) and then increases again at larger radius. Both \(h_3\) and \(h_4\) show small non-zero values but there is no clear trend. For the

\[ h_3 = \frac{v_3 - v_2}{2\sigma} \]

\[ h_4 = \frac{v_4 - v_2}{2\sigma} \]

NGC 3379 is a member of the Leo-I group and is a well observed elliptical, classified as E1 in RC3.

For the major axis, rotation decreases at \(r \approx 4″\) and then increases again at larger radius. Both \(h_3\) and \(h_4\) show small non-zero values but there is no clear trend. For the
Figure A3. Major and minor axis observations for NGC 3379 (PA 71° and 161°, respectively). The seeing for both observations was approximately 0.8′′.

For the major axis spectrum, the most notable features are the non-zero values of $h_3$ for $2'' < |r| < 7''$ (see Figure A3). $h_4$ is zero for these radii. For the minor axis, both $h_3$ and $h_4$ are consistent with zero close to the galaxy centre, becoming non-zero at greater radii. The minor axis also shows non-zero velocities. It should be noted that the minor axis spectrum was smoothed considerably in the spatial direction in order to account for chromatic focus variations. The non-zero measurement of $h_3$ for the major axis and the detection of diskiness by L95 at similar radii, support the existence of a central disk component.

A5 NGC 3608

NGC 3608, a member of the Leo II group, is classified as E2 in RC3 and E1 in RSA. This galaxy was one of the first to be recognised to contain a KDC (JS88). The counterrotation of the galaxy core was suggested by JS88 to be the result of an interaction with another galaxy, without full merging, which caused the motion of the outer parts to be reversed. NGC 3608 is one of several KDC candidates imaged by C97. From measurement of the $V-I$ colour gradient, C97 found no significant stellar population differences between the core and surrounding galaxy of NGC 3608. They found the ellipticity increased from a value close to zero at $r \approx 0.1''$, to $\epsilon \approx 0.2$ at $r \approx 4''$, and NGC 3608 to be slightly boxy for radii outside 5′′.

The profiles of $h_3$ and $h_4$ for both the major and minor axes, are asymmetric about the galaxy kinematical centre (see Figure A5). A small amount of rotation is detected along the minor axis. The measured velocity along the minor axis for $|r| > 10''$ is consistent with zero rotation. Since NGC 3608 has a counterrotating KDC, the LOSVD is likely to be more accurately described by a two-component parameterization.

A6 NGC 4339

NGC 4339 is a member of the Virgo cluster and classified as E0 in RC3 and S0$^{12}$ in RSA, this galaxy is intermediate between an elliptical and S0 galaxy. For this galaxy, the most striking result is a large positive value of $h_4$ at almost all radii for both, the major and minor axis. For most measurements $h_3$ is non-zero along the major axis and consistent with zero for the minor axis (see Figure A6).

A7 NGC 4387

NGC 4387 is a member of the Virgo cluster and classified as elliptical in the RC3. This galaxy was one of 8 of the 45 ellipticals imaged by L95, suspected to contain a nuclear star cluster. Such a component was proposed to explain an upturn in the measured surface brightness towards the HST resolution limit.

Both major and minor axis observations show a noticeable dip in $\sigma$ for the galaxy centre (see Figure A7). For $0'' < r < 5''$ along the minor axis, $h_4$ is slightly positive. For the major axis, $h_3$ is slightly non-zero for $1.5'' < |r| < 5''$ and positive for $r \geq 7''$. $h_4$ is positive for $r \leq -5''$. Outside

© 2001 RAS, MNRAS 000, 000–000
LOSVDs of low-luminosity elliptical galaxies

Figure A4. Major and minor axis observations for NGC 3605 (PA 290° and 200°, respectively). The minor axis observation was subject to significant smoothing during focus corrections, i.e. a maximum Gaussian smoothing of 1.44′′ was applied. For the major axis spectrum, a maximum smoothing of 0.69′′ was required. The seeing for both observations was ∼1′′; the total effective smoothing in the spatial direction is therefore 1.75′′ and 1.21′′ for the minor and major axis observations, respectively.

Figure A5. Measurements for major and minor axes of NGC 3608 (PA 81° and 351°, respectively). Focus corrections were applied for both spectra corresponding to a maximum Gaussian smoothing of 0.99′′ in both cases. The seeing was approximately 1′′ for both spectra. The total smoothing in the spatial direction was therefore ∼1.5″.

~ 4″ this galaxy was observed by P90 to have predominantly boxy isophotes.

The central decrease in σ for both axes suggests that a separate, more rotationally supported component is present at the galaxy centre.

NGC 4458

NGC 4458 is a member of the Virgo cluster and is classified as an E0 intermediate elliptical galaxy in RC3. Studied by L95, its ellipticity was measured to decrease from a value of ∼0.5 at r ∼0.5″ to close to zero at r ∼7.5″.

Our velocity measurements along the major axis show a clear signature of a KDC within |r| < 5″ and a maximum rotation speed of ∼30 km s⁻¹ (see Figure [A8]). At radii |r| >
Figure A6. Major and minor axis observations for NGC 4339 (PA 20° and 110°, respectively). Focus corrections applied to both spectra were small with $0''.65$ and $0''.50$, respectively. The seeing for both observations was approximately $0''.5$. Major axis measurements of rotation have been multiplied by -1 for display purposes.

Figure A7. Major and minor observations for NGC 4387 (PA 142° and 52°, respectively). Focus corrections corresponding to smoothing of $0''.86$ and $0''.76$, respectively, were applied. The seeing for both observations was $\sim 1''$; the total effective smoothing in the spatial direction is therefore $1''32$ and $1''26$.

A9 NGC 4464

NGC 4464 is a member of the Virgo cluster and has an uncertain classification as a spiral galaxy in RC3. Observed by L95, $a_4$ was measured to be almost zero for the central $4''$, and ellipticity $\epsilon \sim 0.35$ for $1'' \lesssim r \lesssim 10''$.

For radii $|r| \lesssim 10''$ along the major axis, significant asymmetrical and symmetrical deviations of the LOSVD from a Gaussian are indicated by non-zero $h_3$ and $h_4$ (see Figure A9). The measurements of $h_4$ are of large amplitude.
Figure A8. Major and minor axis observations for NGC 4458 (PA 5° and 95°, respectively). The seeing for both observations was approximately 0″8.

and change sign with increasing radius. The large amplitude of $h_3$ for the major axis suggests the presence of multiple components of different kinematics along the line-of-sight. For $|r| \lesssim 5″$, the measurements are consistent with the superposition of a bulge and an additional, more rotationally supported, component. At greater radii, the rotation begins to decrease suggesting that the more rotationally supported (perhaps disk) component has a scale-length of $\sim 5″$, and that at $|r| > 5″$ a more slowly rotating bulge component begins to dominate the galaxy light. We note that the kinematic measurements for this galaxies are similar to those of NGC 5582.

Figure A9. Major and minor axis observations for NGC 4464 (PA 5° and 95°, respectively). Focus corrections applied to both spectra were 0″61 and 0″75, respectively. The seeing for both observations was $\sim$1″0. Measurements are therefore independent only on spatial intervals greater than $\sim$1″25. Major axis measurements of rotation have been multiplied by -1 for display purposes.

A10 NGC 4468

NGC 4468 is a member of the Virgo cluster and has an uncertain classification as S0 in the RC3. Our exposures for the major and minor axes of NGC 4468 were too short to provide good spatial detail for the LOSVD higher order terms. Taking our errors into account $h_3$ is almost entirely consistent with zero for both the major and minor axes. $h_4$
shows negative values for both major and minor axis (see Figure A10).

Probably a low surface brightness dwarf elliptical or S0 galaxy, the measured rotation and velocity dispersion for this galaxy are very low, with \( v / \sigma \sim 1.0 \). These measurements mark the limits achievable for the spectral resolution of our data.

A11 NGC 4478

NGC 4478 is a member of the Virgo cluster. While classified as E2 in both RC3 and RSA, this elliptical is classified as a compact elliptical by Prugniel et al. (1987). They argue that NGC 4478 had been tidally-truncated by its nearby neighbour M87. NGC 4478 has been studied with HST by vdB94. In Figure A11 we show their measurements along the major axis of \( \epsilon, \) PA and \( a_4 \) (kindly supplied by F.C. van den Bosch). Also shown are the measurements of \( \epsilon \) and PA taken from P90.

In Figure A11 measurements of rotation, \( \sigma, h_3 \) and \( h_4 \) for \( |r| < 10'' \), provide strong indications of a central component, decoupled from the surrounding galaxy. Measurements of \( \sigma \) and \( h_4 \) for this range of radii, are asymmetric, and rotation and \( h_3 \) are not point-symmetric about the galaxy centre, most notably along the major axis. This could be the result of considerable isophote twisting measured by vdB94 for \( |r| < 5'' \), such that the measured PA deviated by up to 10° from that of our major axis observation (i.e., PA 145°) (see Figure A13). Observations obtained for the photometric axes of the main galaxy may not therefore coincide with the similar axes of a distinct component. A central decrease in \( \sigma \) is measured for both, minor and major axes. For the major axis, a significantly non-zero value of \( h_3 \) is measured for \( |r| < 5'' \), and \( h_4 \) is positive for \( 0 \leq r \leq 3'' \). For the minor axis, \( h_3 \) is slightly non-zero for \( |r| < 2'' \), and \( h_4 \) becomes slightly negative outside \( r = 3'' \).

Two additional interesting features of the photometry of vdB94 (Figure A12) are the significant measurement of diskiness for the inner 2'' and the sharp increase in ellipticity for \( |r| \lesssim 1.5'' \). These two results offer strong support to the idea that a disk component resides at the galaxy centre. From the study of residual maps of their photometry, vdB94 were unable, however, to state conclusively that such a component was observed.

The asymmetric LOSVDs along the major axis (i.e., non-zero measurement of \( h_3 \)) together with the positive measurement of \( h_4 \) for both axes close to the galaxy centre, are consistent with the detection of a separate kinematical component with orbital motion across the line-of-sight. The central dip in \( \sigma \), for similar radii, suggests that this component is more rotationally-supported than the surrounding bulge component. Taken together these results may be consistent with the detection of a central disk population.

The kinematics of this galaxy are clearly complex. Two-dimensional maps of the velocity field, available using integral field unit spectroscopy, would greatly enhance the study of its dynamics.

A12 NGC 4551

NGC 4551 is a member of the Virgo cluster and has an uncertain classification as elliptical in RC3. Our kinematic measurements are presented in Figure A13. This galaxy was studied by both, P90 and L95. The photometric measurements of L95 found NGC 4551 to have “disky” isophotes for \( 1'' \lesssim |r| \lesssim 4'' \). As for NGC 4387, L95 have postulated that NGC 4551 may contain a central stellar nucleus. P90 measure NGC 4551 to become increasingly “boxy” from \( r \sim 4'' \) to \( r \sim 10'' \), and at greater radii \( a_4 \) tends to zero.

For the major axis \( h_3 \) is non-zero for \( |r| \lesssim 5'' \). \( h_4 \) shows
non-zero values close to the galaxy centre. For the minor axis $h_4$ changes only slightly with radius and is almost consistent with a value of zero.

Rotation is measured for the major axis and no rotation is detected for the minor axis. A small central decrease in $\sigma$ is clearly observed for the minor axis. For the major axis this effect is less pronounced. The dip in central velocity dispersion and the measured LOSVD asymmetry for $|r| \lesssim 5''$ along the major axis may be consistent with the detection of a distinct central component of orbital motion across the line-of-sight.

Figure A12. Our measurements of $h_3$ for the major axis of NGC4478, are shown along with photometric measurements of $\epsilon$, PA and $a_4$ from the literature; vdB94 filled circles, P90 open triangles. Measurements of $h_3$ have been folded by multiplying measurements for negative values of radius by -1.

A13 NGC 4564

NGC 4564 is a member of the Virgo cluster and classified as E6 in both RC3 and RSA. Measurements of $v$, $\sigma$, $h_3$ and $h_4$ are given in Figure A14. This galaxy has been studied by vdB94 using HST photometry and in Figure A15 major axis measurements of $h_3$ obtained here are compared with the photometric measurements of $\epsilon$, PA and $a_4$ from vdB94.

Non-symmetric LOSVDs are detected along the major axis by non-zero $h_3$ for $|r| \gtrsim 5''$. $h_4$ is consistent with zero. For the minor axis $h_3$ is non-zero for $-9'' < r < -5''$ and $r \sim 9''$, $h_4$ is positive for $|r| \gtrsim 5''$.

In Figure A15, the most interesting results from the photometry are the measurement of negative $a_4$ and hence boxiness for $r \sim 2''$, and measurement of diskiness for $|r| \gtrsim 10''$, isophote twisting for $r < 2.5'$, and gradually increasing measurement of $\epsilon$ with radius. The measurements of $a_4$ for different radii suggest that two separate components are being detected: within the inner 6'' the measurements of boxy isophotes are consistent with existence of a central bulge; diskiness for $r \gtrsim 10''$, where rotation is still measured to increase with radius, and the gradual increase in $\epsilon$ with radius, are consistent with the detection of a disk component. Measurements are consistent with detection of a disk component embedded within a more slowly rotating bulge.

A14 NGC 5582

NGC 5582 is classified as elliptical in RC3. Measurements are presented in Figure A16. For the major axis, $h_3$ is significantly non-zero for $|r| < 14''$ and reaches a maximum amplitude for radii at which there is a knee in the rotation curve. $h_4$ changes significantly in value with radius. For the
inner 10″, the measurements closely resemble those for the major axis of NGC 4464.

Examples of actual fits to the recovered galaxy broadening function, i.e. the recovered LOSVD shape, are given in Figure 1 in the main part of this paper. For \( r < -1″ \), the LOSVD is clearly asymmetric and for \( r < -2″ \) there is clear evidence for the existence of two separate kinematical components, one of which has greater mean velocity along the line-of-sight and appears to dominate the measured kinematics. This is consistent with detection of a separate bright disk component, or a bulge component of high rotational support.

APPENDIX B: COMPARISONS WITH OTHER AUTHORS

Comparisons are made between measurements of \( v, \sigma, h_3 \) and \( h_4 \) obtained here and measurements obtained previously by other authors (BSG94, Kormendy et al. 1998, hereafter K98, and SSH99). Measurements have been obtained for the major axis of NGC 3379, NGC 3377 and NGC 4564...
by BSG94, for the major axis of NGC 3379 by SSH99, and for rotation velocity and $\sigma$ of NGC 3377 by K98. The PAs of different observations for a given galaxy differed slightly, but in all cases by less than 5°. Results of comparisons are given in Figure B1.

There is in general very good agreement between our measurements and those of other studies. Disagreements can be attributed to the different seeing conditions, instrumental set-ups and exposure times. For NGC 3377 there is remarkably good agreement for the higher-order terms $h_3$ and $h_4$. There are however differences in the measurements of rotation and $\sigma$ at the galaxy centre. The better spatial resolution of our own observations and particularly those of K98 are able to resolve the steeply rising rotation curve; the $\sigma$ measurements of K98 are also lower for these radii than both our own and those of BSG94, reflecting their improved resolution of the rotation curve. For NGC 3379 our measurements of rotation, $\sigma$, $h_3$ and $h_4$ agree well with the measurements of BSG94 and SSH99. For NGC 4564, there is disagreement between our measured values of $h_3$ for $r > 12''$ and those of BSG94.

**Figure A15.** $h_3$ measurements for the major axis of NGC 4564 obtained here are plotted together with the photometric measurements of van den Bosch et al. (1994) (i.e. measurements of $a_4$, ellipticity ($\epsilon$) and PA as functions of radius). Measurements of $h_3$ have been folded by multiplying measurements for negative values of radius by -1.

**Figure A16.** Major and minor axis observations for NGC 5582 (PA 25° and 115°, respectively). Focus corrections applied for the major and minor axis spectra corresponded to a maximum Gaussian smoothing of 0.74 and 1.30, respectively. The seeing for the minor axis observation was 1''; measurements for this spectrum can not be assumed to be independent on spatial intervals $\simeq 1''$. 
Figure B1. Comparison of measurements of rotation velocity, $\sigma$, $h_3$ and $h_4$ for galaxies in common with those studied by BSG94, SSH99 and K98. Measurements obtained in this study are indicated by open circles and asterisks for measurements in the direction and away from the direction of the PA of observation, respectively. BSG94 measurements are connected by dot and dashed lines for measurements in and away from the direction of the PA, respectively. SSH99 measurements are given by open and crossed square symbols for measurements in and away from direction of PA. K98 measurements are given by open and solid triangle symbols for measurements in and away from PA direction.