

# Probing the 2-D Kinematic Structure of Early-Type Galaxies Out to 3 Effective Radii

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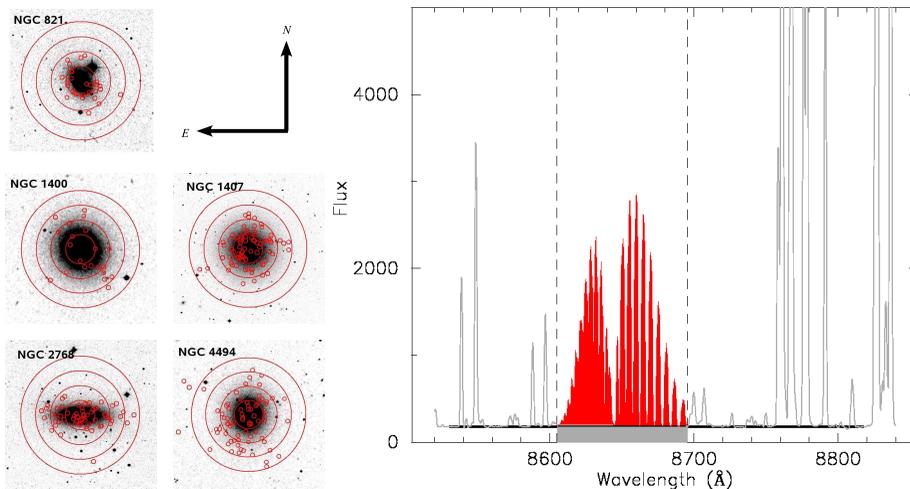
**Abstract.** We detail an innovative new technique for measuring the 2-D velocity moments (rotation velocity, velocity dispersion and Gauss-Hermite coefficients  $h_3$  and  $h_4$ ) using spectra from Keck DEIMOS multi-object spectroscopic observations. The data are used to reconstruct 2-D rotation velocity maps.

Here we present data for one of five early-type galaxies whose kinematics we have measured out to  $\sim 3$  effective radii (see [1]). From these data 2D kinematic maps are constructed. We show such analyses can provide significant insights into the global kinematic structure of galaxies, and, in some cases, challenge the accepted morphological classification. Our results are of particular importance to studies which attempt to classify galaxies by their kinematic structure within one effective radius, such as the recent definition of fast- and slow- rotator classes by the SAURON project.

## INTRODUCTION

The development of integral field units (IFUs), such as the SAURON instrument, have given new impetus to the field of galaxy kinematics, as these provide 2-D maps of each of the elements of the LOSVD. This allows the definition and estimation of a number of important new parameters that can be averaged over the surface of galaxies in a self-consistent way. However, most such studies are confined to within  $1 R_{\text{eff}}$ , thus only sampling 50% of the baryonic mass,  $\sim 5\%$  of the total mass and  $\sim 10\%$  of the angular momentum. Here we report a new method for deriving 2-D kinematic maps out to  $\sim 3 R_{\text{eff}}$  in the halos of nearby early-type galaxies. By extending the region studied to such radii we encompass more than 85% of the baryonic mass, 15% of the total mass and 30% of the angular momentum. This technique therefore has great potential value for the dynamical modeling of galaxies.

Our analysis involves the measurement of stellar LOSVDs from deep Keck DEIMOS multi-object spectroscopic observations in Calcium triplet region of the near infrared. Specifically, we measure rotation velocity, velocity dispersion and the Gauss-Hermite coefficients  $h_3$  and  $h_4$ , out to  $\sim 3 R_{\text{eff}}$  in the halos of five nearby early-type galaxies (only one of which is presented here). The galaxies in our sample are nearby, early-types selected with the intention of obtaining spectra of their globular clusters in order to analyse their kinematics, and hence probe the mass profile of their host galaxy halos. The results reported here, however, concern the kinematics of the stellar halos of the



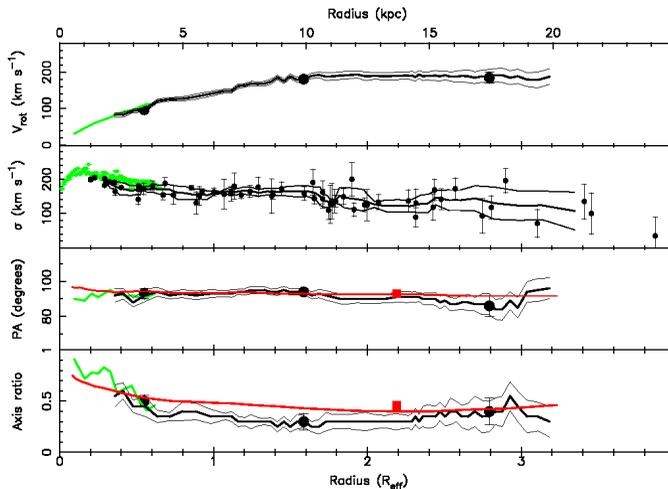
**FIGURE 1.** **Left:** DSS images of the 5 target galaxies. Small circles mark the location of slits from which galaxy background spectra were obtained. Large circles represent 1, 2, 3 and 4 effective radii. Note that sky estimates were taken from between 6 and 7 effective radii. **Right:** Shows the region used in the calculation of the sky index in a scaled sky spectrum. The index is defined as a ratio, i.e. excess flux in the central band (shaded counts above continuum) divided by continuum flux (shaded counts below continuum).

*host galaxies themselves* that were simultaneously observed in the DEIMOS slits.

## DATA REDUCTIONS AND ANALYSIS

Data reductions were carried out using the DEIMOS DEEP2 pipeline software. This package produces a variety of outputs from the raw DEIMOS data, including both object and 'sky' spectra. The data reported here probe the kinematics of the stellar populations in the galaxy halos. These are based on the 'sky' spectra that were subtracted from the globular cluster spectra (the prime targets of the observation, see [2]). These actually consist of a co-addition of the true sky and the background galaxy light. In order to extract the background galaxy we used what we refer to as the 'true sky spectrum'. This was estimated from spectra obtained at high galacto-centric radii ( $>6 R_{eff}$ ) where halo light is faintest. By use of an index designed to estimate the sky intensity in each spectrum (Fig. 1), the appropriately weighted 'true sky spectrum' could then be subtracted from each of the DEIMOS 'sky' spectra in the science region ( $<4 R_{eff}$ ; See Fig. 1). This process leaves the background galaxy halo light (See [1] for full details).

The analysis proceeded by the measurement of velocity moments ( $V$ ,  $\sigma$  and the Gauss-Hermite coefficients  $h_3$  and  $h_4$ ) using the pPXF code of [3]. This pixel fitting code allows the exclusion of regions of the spectra contaminated by sky-line residuals - an important feature when working in the near infrared. The kinematic parameters so derived were then analysed by galacto-centric radius and position angle using a form of 'kinemetry'



**FIGURE 2.** NGC 2768. Radial profiles of the major axis rotation velocity ( $V_{\text{rot}}$ ),  $\sigma$ , kinematic and photometric PA ( $\text{PA}_{\text{kin}}$  and  $\text{PA}_{\text{phot}}$ ) and axis ratio ( $q=1-\epsilon$ ). The physical radial distances are given in kiloparsec on the top axis. The  $\sigma$  data points are the individual measured values, with bold lines representing a rolling average of 5 points and their  $1-\sigma$  errors. For all other parameters the dark data points represent the values of our fits to independent regions, while the results of rolling fits to the data and their  $1-\sigma$  errors are indicated as lines. Grey data points and lines at small radii are from our analysis of the SAURON data. The squares in PA and axis ratio mark the 2MASS photometric values at the radius of the K band 20th magnitude isophote, while the smooth lines show the R band photometric data from the literature. Overall agreement with the literature values is very good.

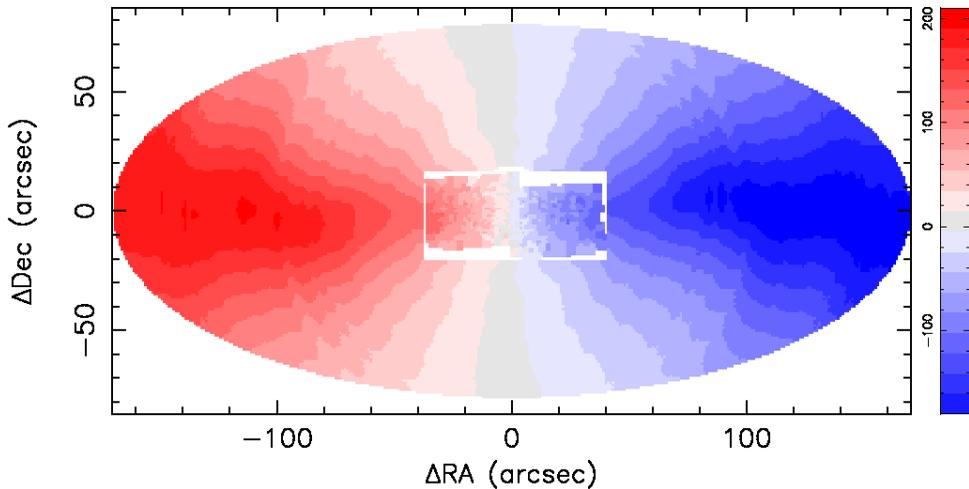
as detailed by [4]. From these results 2-D kinematic maps could then be constructed.

## RESULTS AND CONCLUSIONS

For all 5 early-type galaxies in our sample we were able to demonstrate good agreement between our results and literature values. This is evidenced by the good agreement between our data and the SAURON data seen in the plot of radial profiles in NGC 2768 (Fig. 2), as well as the re-constructed rotation velocity map (Fig. 3). The data for NGC 2768 also strongly suggests a S0 morphology, despite the official classification as an elliptical galaxy. Indeed, it became apparent that all five galaxies in our sample show some evidence for a disc or disc-like kinematic components.

NGC 2768 also exhibits good agreement between kinematic and photometric PAs and axis ratios (Fig. 2). In fact, PAs were in good agreement in all five galaxies. However, in some galaxies, photometric and kinematic axis ratios differ significantly.

We were able to show that, in all five galaxies, between 1–3 effective radii the velocity dispersion declines very slowly, if at all. For the two galaxies with velocity dispersion profiles available from planetary nebulae data we find very good agreement with our stellar profiles. We find a variety of rotation profiles beyond 1 effective radius, i.e rotation speed remaining constant, decreasing *and* increasing with radius. These results are of



**FIGURE 3.** NGC 2768. Reconstruction of the 2-D rotation velocity map using the rolling fits of previous figure. The outer boundary of the map has been chosen to reflect the photometric axis ratio of the galaxy (0.46). The velocity scale (in  $\text{km s}^{-1}$ ) is shown on the right. Also shown is the SAURON velocity map of the central regions of the galaxy. The agreement between the data can again be seen to be extremely good.

particular importance to studies which attempt to classify galaxies by their kinematic structure within one effective radius, such as the recent definition of fast- and slow-rotator classes by the SAURON project. Our data suggests that the rotator class may change when larger galacto-centric radii are probed. Our results also have important implications for dynamical modeling of early-type galaxies.

## REFERENCES

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