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The Intrinsic Ellipticity of Spiral Disks

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Abstract.
We have measured the distribution of intrinsic ellipticities for a sample of 28 relatively face–on spiral disks. We combine Hα velocity fields and R and I-band images to determine differences between kinematic and photometric inclination and position angles, from which we estimate intrinsic ellipticities of galaxy disks. Our findings suggest disks have a log-normal distribution of ellipticities ($\overline{\epsilon} = 0.06$) and span a range from $\epsilon = 0$ (circular) to $\epsilon = 0.2$. We are also able to construct a tight Tully-Fisher relation for our face-on sample. We use this to assess the contribution of disk ellipticity on the observed Tully-Fisher scatter.

1. Disk Ellipticity Survey

Binney (1978) showed triaxial halos could affect disks by inducing warping and twists. In particular, the axis ratio of halos lead to disks which are intrinsically elliptical (Franx & de Zeeuw 1992; Jog 2000). Hence the ellipticity of disks may plausibly be used to estimate the axis ratios of dark matter halos. However, the inability to disentangle the ellipticity from the phase angle of this distortion makes such measurements difficult (e.g. Zaritsky & Rix 1995; Schoenmakers 1999). Andersen et al. (2001) presented a method which removed this degeneracy and yielded unique solutions for the disk ellipticity of nearly face-on galaxies by comparing kinematic and photometric inclination and position angles. This method assumes differences between these angles are solely the effect of ellipticity and not some other distortion.

Here we present results of a larger study to define the distribution of disk ellipticities and to establish if ellipticity is related to other physical quantities, e.g., Tully-Fisher (TF) scatter. A sample of 39 galaxies were selected from the Principal Galaxy Catalog (Paturel et al. 1997) which have (1) t-types between 1.5–8.5, (2) axis ratios close to unity, (3) apparent disk sizes commensurate with the field of view of the integral field unit, DensePak, on the WIYN 3.5m telescope (Barden, Sawyer & Honeycutt 1998), and (4) low galactic absorption. We also required galaxies in the sample to be unbarred, isolated and have constant photometric position angles at three scale lengths.

R and I-band images were acquired at the WIYN 3.5m, KPNO 2.1m, McDonald Observatory 2.7m telescopes. We used these images to measure axis ratios and position angles in a way designed to be unaffected by warps or spiral

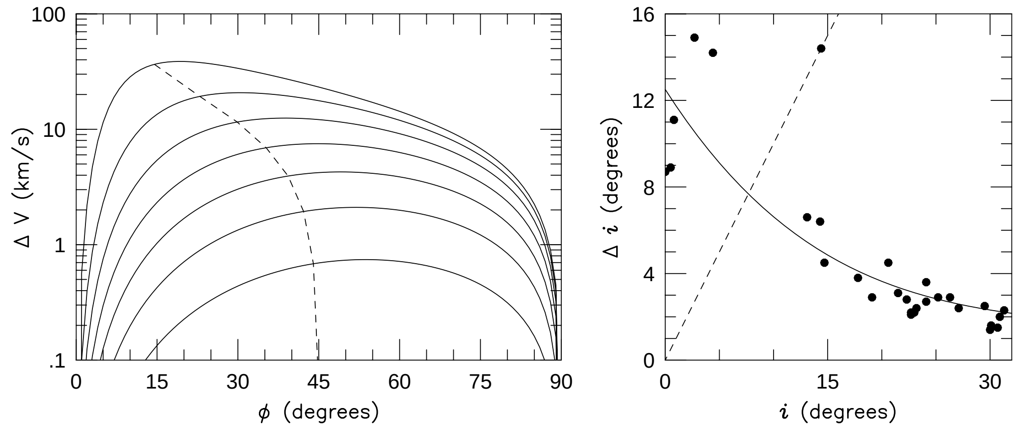

Figure 1. **Left Panel:** Differences in projected velocity as a function of ϕ (the angle from the major axis in the *observer's* frame) between rotating disks with inclination differences of 5°. These differences assume (1) measurements are made on the flat part of the rotation curve, (2) $V_{\rm rot} = 160 \sin i$ km/s in the mean, and (3) orbits are circular. The solid curves represent mean inclinations of $15°, 25°, 35°, 45°, 55°, 65°$ and 75°. The dashed line represents $\theta = 45°$ for each of these different inclinations, where θ is the angle from the major axis in the *galaxy* plane. Classical tilted-ring fits do not utilize data to right of dashed line, thereby missing over half the signal used to estimate inclination. **Right Panel:** The solid curve is our Monte Carlo prediction of inclination errors for velocity fields "observed" with two DensePak pointings and fit with a single inclined-disk velocity-field model, while points are errors measured using χ^2 intervals in fits to data. The dashed line represents $\Delta i/i = 1$. Galaxies with $i > 15°$ have inclination errors $\Delta i < 5°$ which are sufficiently small to study the TF relation.

structure (see Andersen et al. 2001). Hα velocity fields were obtained using DensePak, feeding the WIYN Bench Spectrograph used with the 316 lines/mm echelle grating to cover 6500Å$< \lambda\lambda <$ 6900Å, with an instrumental FWHM of 0.51 Å (22.5 km/s). Multiple DensePak pointings allowed us to map Hα velocity fields beyond 2.5 disk scale lengths. We modeled observed velocity fields to derive kinematic inclinations and position angles — parameters critical to estimating disk ellipticity.

1.1. Velocity-Field Modeling

Most galaxies in our sample do not show signs of rotation curve asymmetries, warps, solid body rotation, or spiral structure. Therefore, we adopted a single, inclined, differentially rotating, circular disk ("monolithic") model to fit the DensePak Hα velocity fields instead of tilted ring models (e.g., Begeman 1989). There were two major advantages to our approach: (1) A monolithic velocity-field model uses all data to constrain the fit; and (2) a monolithic velocity-field model is better able to model low-inclination disks because tilted ring fits tend to diverge unless the fit is weighted by $|\cos\theta|$ (θ is an angle measured from a galaxy's major axis in the galaxy plane) and data with $|\theta| > \theta_{max} = 45°$ is removed (Begeman 1989). However, the greatest differences between two velocity-field models with slightly different inclinations occur at $\theta > 45°$, precisely where tilted-ring fits often do not consider the data (left panel of Figure 1). Since differences between velocity fields of different inclination decrease with inclination, it is imperative to use data at all azimuthal angles to accurately fit velocity-field models at low inclinations, i.e. $i < 30°$ (right panel of Figure 1). A hyperbolic tangent rotation curve was sufficient to fit the shape of rotation curves in our sample with a minimum of free parameters. Our model had the following free variables: inclination, position angle, center, central velocity, observed rotation velocity, and hyperbolic tangent scale-length. The results of the model fits indicate our approximation that orbits are circular appears to be acceptable; for $\epsilon_D < 0.2$ the model inclination and position angles derived from circular versus elliptical orbits would be quite similar. We determined kinematic parameters for 36 of 39 galaxies using our fitting procedure. Of the three galaxies for which we could not fit velocity-field models, two were at very low inclinations, while the third had insufficient data.

1.2. Results

We derive ellipticities for the 28 of 39 galaxies for which accurate measures of the photometric and kinematic indices exist. We find a mean disk ellipticity of $\overline{\epsilon_D} = 0.076$ If we assume the halo potential is non-rotating and has a constant elliptical distortion, we can estimate a halo ellipticity of $\overline{\epsilon_\Phi} = 0.054$ which is consistent with previous estimates of halo ellipticity (Rix & Zaritsky 1995; Schoenmakers 1999). Our unique solutions for disk ellipticity also allow us to determine the distribution of ellipticities for our sample, which we find is well-fit by a log-normal distribution with a mean and standard deviation on $\ln(\epsilon_D)$ equal to -2.82±0.73 ($\epsilon_D = 0.060^{+0.064}_{-0.031}$, left panel of Figure 2).

2. Face–On Tully–Fisher Relation

To demonstrate the precision and reliability of our kinematic inclinations, we construct a TF relation for 24 galaxies which have reliable photometry and span a range of inclinations from 15°–35° (a mean of 26°). After applying color corrections, we find our data match Courteau's (1997) TF relation quite well (central panel of Figure 2). Courteau's sample galaxies have comparable scale lengths, colors, and surface brightnesses and distances as ours, but inclinations greater than 40° (with a mean of 64°). Two notable advantages of using face–on galaxies in TF relation are: Internal absorption corrections are minimal and the effect of quantities such as lopsidedness and ellipticity (indices most easily measured in face-on systems) upon TF scatter can be assessed.

The TF scatter for our sample is quite small (only 0.44 mag) – quite similar to the dispersion of Courteau's sample (0.46 mag). The distribution of residuals to the TF relation are Gaussian except for four galaxies which appear to be outliers. There is a correlation between these outliers and kinematic asymmetry: Of the 5 galaxies in this sample which exhibit strong kinematic asymmetries in their rotation curves, three are outliers. If we exclude the galaxies with strong kinematic asymmetries from our analysis, the observed TF scatter is 0.36 mag.

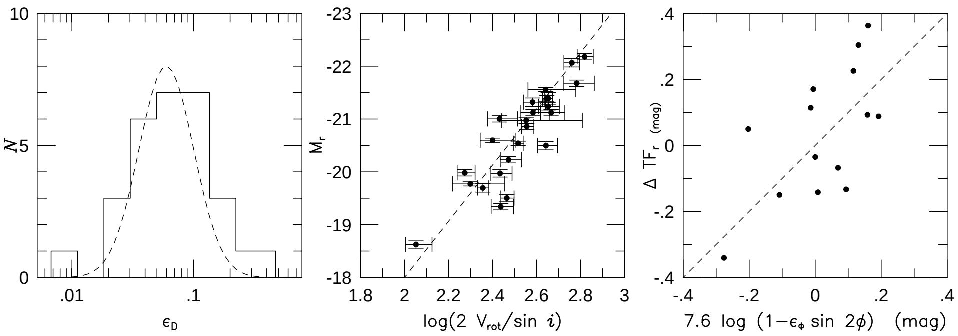

Figure 2. **Left Panel:** Distribution of disk ellipticities for our sample of 28 galaxies. This distribution is well-fit by a log-normal distribution (dashed line) characterized by a mean ellipticity $\overline{\epsilon_D} = 0.060$. **Center Panel:** A Tully-Fisher relation for a sample of galaxies with a mean inclination of 26°. The dashed line represents the best fit TF relation to a subsample of galaxies in the quiet Hubble flow taken from Courteau (1997) Only 0.44 magnitudes of scatter was exhibited about this relation. **Right Panel:** Component of TF scatter due to assuming circular orbits for an elliptical potential (Franx & de Zeeuw 1992; Table 1) versus TF scatter for our sample of nearly face-on galaxies.

Franx & de Zeeuw (1992) suggested that disk ellipticity may be a source of TF scatter. If we assume a simple, non-rotating model for the halo potential, we can describe the expected contributions of disk ellipticity to TF scatter in simple terms. While other astrophysical sources are expected to contribute a large fraction of the TF error budget, we do find a statistically significant correlation between disk ellipticity and TF scatter (right panel of Figure 2). Constraining the contribution of ellipticity to TF scatter places limits on other astrophysical sources of TF scatter, including variations in disk mass-to-light ratios. This work was supported by NSF grant AST-9970780.

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