Disks of Galaxies : Kinematics, Dynamics and Perturbations
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WIYN Integral-Field Kinematics of Disk Galaxies

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Abstract.
We have completed a new fiber array, SparsePak, optimized for low-surface-brightness studies of extended sources on the WIYN telescope. We are now using this array as a measuring engine of velocity and velocity-dispersion fields of stars and ionized gas in disk galaxies from high to low surface-brightness. Here we present commissioning data on the velocity ellipsoids, surface densities and mass-to-light ratios in two blue, high surface-brightness, yet small disks. If our preliminary results survive further observation and more sophisticated analysis, then NGC 3949 has $\sigma_z/\sigma_R \gg 1$, implying strong vertical heating, while NGC 3982's disk is substantially sub-maximal. These galaxies are strikingly unlike the Milky Way, and yet would be seen more easily at high redshift.

1. SparsePak

SparsePak contains a 76×77 arcsec sparsely-packed hexagonal grid of 75, 5-arcsec diameter fibers, which pipe light from the "imaging" Nasmyth focus to the versatile Bench Spectrograph on the WIYN 3.5m telescope (Bershady et al. 2002). Seven "sky" fibers are placed at ~ 30 arcsec from two grid sides. The large anamorphic demagnification in the echelle-mode of the Bench Spectrograph yields instrumental spectral resolutions of 8000-10,000 and as high as 21,000 with SparsePak – comparable to resolutions obtained with smaller fibers. At the same time, SparsePak has > 90% throughput for $\lambda > 500$nm, and provides nearly 3× the light gathering power over 5× the area as DensePak, the pre-existing WIYN fiber array. These attributes make SparsePak well suited for medium-resolution spectroscopy on extended objects down to low surface-brightness.

2. Disk Stellar Kinematics and Mass to Light Ratios

We have mapped the velocity and velocity dispersion fields in two blue, very high surface-brightness, yet small disks in the Ursa Major cluster (B−R=0.8-1 mag, $\mu_0^{\rm obs}$(B)=19.3-19.5 mag arcsec^{-2}, h_R=0.9-1.7 kpc, Verheijen 1996). NGC 3982 is nearly face-on (i=26°), while NGC 3949 is moderately inclined (i=54°). As such, these photometrically similar galaxies offer projections which enhance measurements of different components of their velocity ellipsoids.

Each galaxy was observed in three spectral regions near 5130Å (MgI), 6680Å (Hα) and 8660Å (CaII-triplet) with FWHM spectral resolutions of 24, 16 and 37 km/s respectively. Stellar absorption-line observations were taken with a single SparsePak pointing while Hα was contiguously mapped in three pointings at

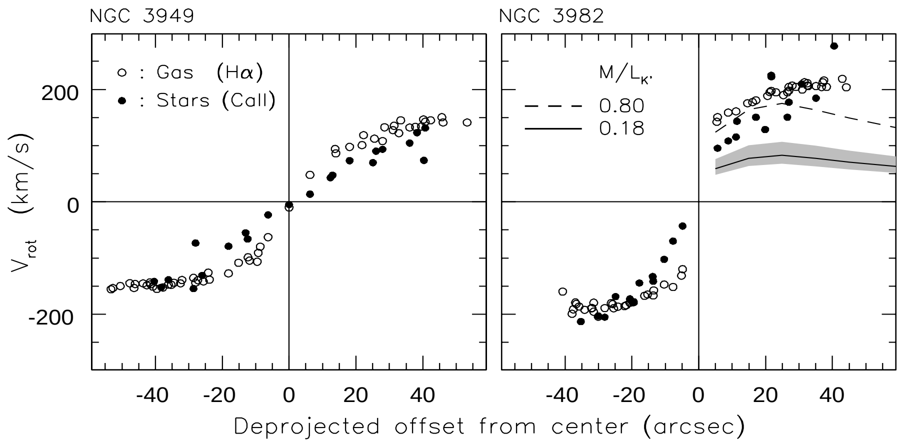

Figure 1. De-projected position-velocity diagrams for stars (CaII-triplet) and ionized gas (Hα) in N3949 and N3982. Note asymmetric drift, clearly visible in the inner, steeply rising regions, approaches zero at large radii. For N3982 we show the stellar contribution for two mass decomposition models which include stars, gas, and a dark halo: a maximum-disk (dashed line), and the substantially (25%) sub-maximum disk implied by the stellar line-widths in Figure 2 (see also Verheijen et al. 2002).

very high S/N. The latter provided high-precision kinematic inclinations (see Andersen & Bershady, these proceedings).

In the inner regions of the galaxy, the signal-to-noise in the absorption-line spectra of individual fibers is high enough to determine the line centroids and widths and to construct stellar velocity fields (Figure 1). The layout of the fibers allows for azimuthal averaging of fibers to improve signal-to-noise in the outer regions (Figure 2). The near face-on orientation of NGC 3982, for example, permits 18 fibers to be combined at a radius of 3.5 h_R. Before averaging, the projected rotational velocities were taken out, using the centroids of the high signal-to-noise Hα lines. In both galaxies this may lead to an overestimate of the inner velocity dispersions. Comparison of the Hα and stellar velocity fields in Figure 1 clearly shows the effects of asymmetric drift inside 1.5 disk scale lengths (h_R). Outside this radius the asymmetric drift approaches zero.

Two results stand out from these initial measurements, illustrated in Figures 2 and 3. First, for NGC 3949, the ratio of major and minor axis velocity dispersions are unity ($\pm$8%), while the epicycle approximation yields $\sigma_\phi/\sigma_R = \sqrt{(1 + d\ln V_c/d\ln R)/2} = 0.75 \pm 0.12$. From this we find the surprising result that σ_z must be much larger than either σ_R or σ_ϕ, implying at face value that NGC 3949 has a dynamically unusual (hot) disk (cf Gerssen et al. 2000).

Second, the velocity dispersion in the disk of NGC 3982 is $\sim$ constant with radius until the last radial datum, where $\sigma^{\rm obs}$ falls to a significantly lower value. (No corrections were applied for contributions from the projected radial and tangential velocity dispersion components – a <13% effect.) We derive a *total* disk mass surface density for a variety of scale heights, based on results from recent work by Kregel et al. (2002), and assuming an isothermal (sech^2) vertical density profile. This mass surface density is at a level $\sim$3.5 higher than the surface density of the Milky Way in the Solar Neighborhood (Kuijken & Gilmore

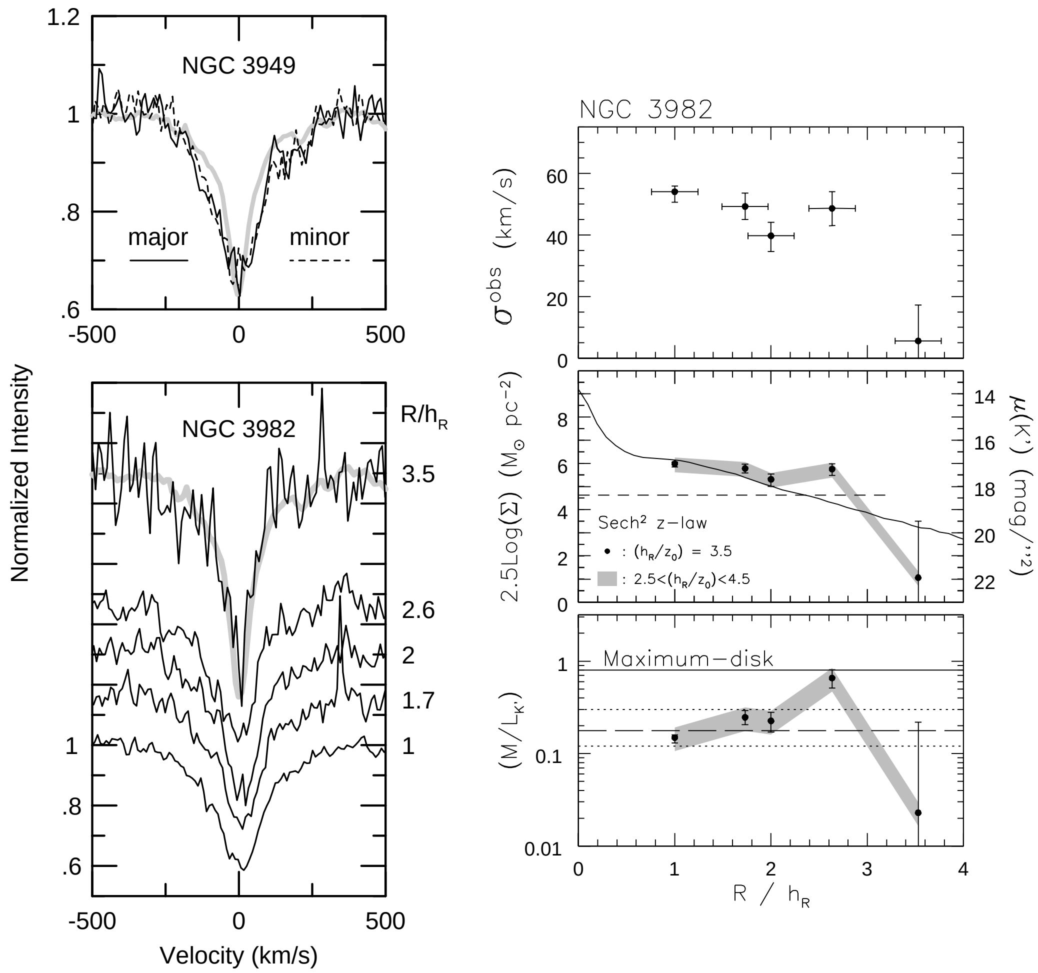

Figure 2. **Left panels.** Stellar line profiles for the deepest CaII line in N3949 (top) and N3982 (bottom). In both panels the grey curve is the observed line for a K0.5-III template star (one of ∼3 dozen template stars spanning a range in $T_{\rm eff}$ and g, observed by drifting each star across many fibers). Major and minor axis profiles in N3949 at $R/h_R = 2$ have nearly identical widths, which, when combined with the epicycle approximation, implies $\sigma_z \gg \sigma_R$. The radial trend in line-width in N3982 is weak for $R/h_R < 3$. **Right panels.** *Top*: Azimuthally averaged stellar velocity dispersions for N3982 in 5 radial bins containing 6-18 fibers (increasing with radius). Dispersions are determined by convolving the K0.5-III stellar spectrum with Gaussians of varying FWHM and finding the best match to the azimuthally averaged galaxy spectra. *Middle*: Inferred mass surface-density for an isothermal, vertical density profile and a range of scale-heights. The dashed line shows the value for the Solar Neighborhood. The solid line shows the radial K' surface brightness profile. *Bottom*: Derived radial dependence of disk M/L in the K' band. The solid line shows the maximum value allowed by the rotation curve. The dashed line is the weighted mean over all radii while the dotted lines map into the width of the grey, shaded curve in Figure 1. This suggests that NGC 3982 has a substantially sub-maximum disk despite the fact that the stellar disk has a very short scale length and an extremely high surface brightness.

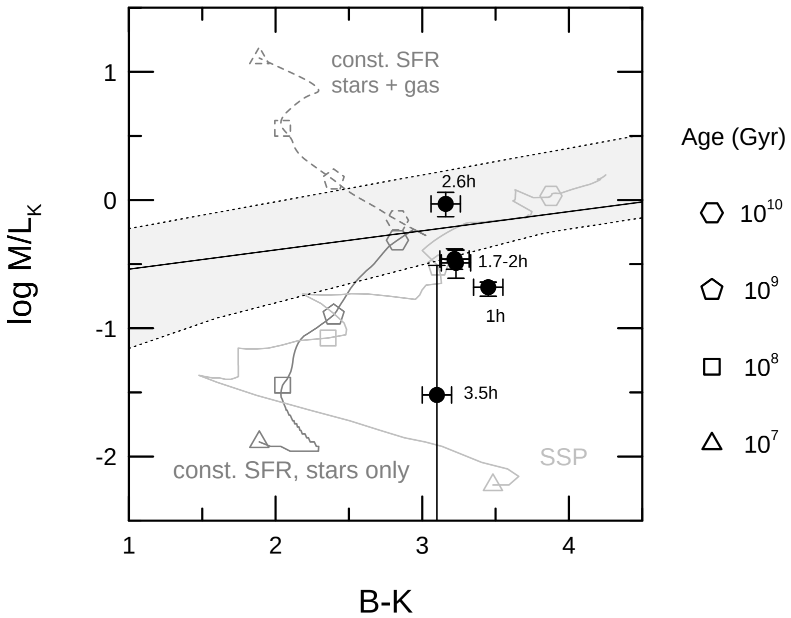

Figure 3. K-band mass-to-light ratio versus B-K color for NGC 3982 at 5 radial bins (marked in units of radial scale-length h_R. The predictions from Bell & De Jong (2001) are shown for their full range of star-formation histories and metallicities (grey shaded region) and favored model (solid line). The shaded lines are single-burst (SSP) and constant star-formation models as a function of age (see symbol key). We find NGC 3982's disk has a wide range of M/L over a small range of B-K color.

1991), and is nearly constant with radius until R/h_R=3. Consequently the mass-to-light ratio of the disk increases with radius for $R/h_R < 3$, while the disk color gets bluer – a trend opposite that indicated by the models of Bell & De Jong (2000). However, our color range is limited, and we must also check whether red super-giants are in abundance in this system. Finally, a weighted radial average of $(M/L_{K'})$=0.18 is used in a rotation curve decomposition shown in Figure 2 which implies a substantially ($\sim$ 25%) sub-maximum, yet very high SB disk (see also Verheijen et al. 2002). This research was supported by NSF/AST-9970780.

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