Discovery of Super-Thin Disks in Nearby Edge-on Spiral Galaxies

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Abstract. We report the identification of a super-thin disk (h_z ∼ 60 pc) in the edge-on spiral galaxy NGC 891. This component is only apparent after we perform a physically motivated attenuation correction, based on detailed radiation transfer models, to our sub-arcsecond resolution near-infrared imaging. In addition to the super-thin disk, we also find several structural features near the center of NGC 891, including an inner disk truncation at ∼3 kpc. Inner disk truncations may be commonplace among massive spiral galaxies, possibly due to the effects of instabilities, such as bars. Having successfully demonstrated our methods, we are poised to apply them to a small sample of nearby edge-on galaxies, consisting both of massive and low-mass spirals.

1. Introduction

Understanding the vertical disk structure of spiral galaxies is crucial for learning about how galaxies form and evolve over time (Samland & Gerhard 2003; Moster et al. 2010), as well as producing an accurate estimate for the baryon content of disks (Bershady et al. 2010a,b). In the Milky Way, with survey measurements of many thousands of individual stars, disk structure can be examined in great detail (e.g. Bovy et al. 2012). When viewed as if it were an external galaxy, the Milky Way’s light distribution can be fit with just three main disk components: the thick disk, containing old stars (scaleheight h_z ∼ 1 kpc); the thin disk, the most dominant light-weighted component (h_z ∼ 300 pc); and a super-thin disk, consisting mostly of young stars (h_z ∼ 100 pc, van Dokkum et al. 1994). The latter component goes by many names in the literature; it is frequently referred to as the ‘young’ or ‘star-forming’ disk. We prefer the term ‘super-thin’ as it carries no assumption about the age of the disk.

The existence of both thin and thick disks in other spiral galaxies, while an uncertainty for many years (van Dokkum et al. 1994), has now been confirmed (Dalcanton & Bernstein 2002; Comerón et al. 2011). However, the ubiquitous presence of dust near the midplane of these galaxies (especially for massive ones most similar to the Milky Way, Dalcanton et al. 2004) prevents easy study of any super-thin components.

Here we present initial results from our ongoing work to map edge-on disk structure, using a combination of high-resolution near-infrared (NIR) imaging and advanced Monte Carlo radiation transfer models to remove the effects of dust and probe vertical surface brightness profiles all the way down to the midplane. Our method is illustrated by its application to NGC 891, but is broadly applicable to all edge-on galaxies.
2. Data and Model

The following is a brief overview of our data and our radiation transfer modeling. Full details of our methodology, both for data reduction and producing our attenuation correction, can be found in Schechtman-Rook & Bershady (2013).

2.1. NIR Data

Data were taken on the WIYN High-resolution InfraRed Camera (WHIRC; Meixner et al. 2010) on the WIYN 3.5 m telescope in 2011 October. NGC 891 is significantly larger in radius than the WHIRC field of view, so three pointings were required to image out to just over ±10 kpc in radius. Sky images were interspersed with data exposures in order to compute an accurate background estimate for such an extended object. The images were processed using in-house reduction software, which performs all aspects of data reduction from initial trimming of the images to creating the final mosaic.

2.2. Attenuation Correction

To compute the attenuation correction we first model NGC 891 using the radiation transfer software HYPERION (Robitaille 2011); a model was created which matched the integrated spectral energy distribution of NGC 891, and images of this model with and without dust were compared to produce a pixel-by-pixel attenuation map. The attenuation in a given pixel was well-predicted by the model’s $K_s$-4.5µm color.

In order to use this color to correct our WHIRC data, we obtained an archival Spitzer IRAC image of NGC 891. While this image is at significantly lower resolution...
Figure 2. JHK$_s$ false-color images of the isolated fast rotators (other than NGC 891) in our sample. The dashed ellipse indicates the inner truncation in visible in our images of NGC 4565.

compared to our NIR data, the intrinsic smoothness of the luminosity profile at 4.5$\mu$m allows us to preserve the resolution of our WHIRC data.

3. Results

3.1. NGC 891

Observed and attenuation-corrected JHK$_s$ false-color images are given in Schechtman-Rook & Bershady (2013). We fit models with up to three discrete disk components, producing best-fitting models using a Levenberg-Marquardt non-linear least-squares fitter. For these initial models we ignored the central 3 kpc of NGC 891 to avoid bulge/bar contamination. We find that three disks are necessary in order to reproduce NGC 891’s intrinsic K$_s$-band surface-brightness at all heights. These three components have very scale-heights to the Milky Way, with the super-thin disk scale-height $h_z \approx 60$ pc.

We then investigated the ability of our models to fit the data within 3 kpc, and found that models with just disks and R$^{1/4}$-law bulges were insufficient. In all, we had to add three new features to our best-fitting 3 disk model: an inner disk truncation for all three disk components at R$\approx 3.1$ kpc; a bar, which was well-approximated by an exponential disk with $h_z \approx 400$ pc; and a nuclear extension of the super-thin disk, which has a scale-length of only 250 pc. An R$^{1/4}$-law bulge is not necessary to reproduce the light profile of NGC 891, and actually results in significantly worse fits if used in place of the nuclear super-thin disk. The light from the bar is roughly equivalent to the light lost due to the inner disk truncation, implying that the bar is composed of stars swept up from NGC 891’s disks.
Figure 3. JHK, false-color images of the two slow-rotators ($V < 90$ km sec$^{-1}$) in our sample. These galaxies show little evidence for dust-lane attenuation but have extensive star-clusters throughout the vertical range of the disk.

3.2. Other Galaxies

In addition to NGC 891, we have a small sample of nearby edge-on galaxies suitable for this analysis. We generally selected systems with properties similar to the Milky Way and NGC 891 (Figure 2); however we have also included some low-mass spirals (Figure 3) as well as a galaxy undergoing a minor interaction (bottom panel of Figure 2). In both figures the images are not attenuation corrected.

Of special note is NGC 4565 (second from bottom panel of Figure 2), which has a clearly visible inner disk truncation. Interestingly this also appears to be the situation in the Milky Way (at least in dust emission, see Robitaille et al. 2012). While three galaxies is too small a sample to draw definitive conclusions, it appears inner disk truncations may be a common feature of massive spiral galaxies.

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