The Shapes of Dwarf Galaxies and their Dark Matter Content: An Opportunity for Gemini

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Abstract: Dwarf irregular galaxies are the most numerous type of galaxy in the universe, and they are both simple and confounding to modern theories of the universe and galaxy evolution. To determine the shapes and dark matter content of this key class of galaxies, we need to understand the stellar kinematics across the entire dIm class. This particularly requires pushing to low luminosity, and hence low surface brightness, systems. These observations require a long (3-5′) slit echelle spectrograph on a large telescope with the ability to achieve an R∼20,000 at 5200 Å with a wide (2-4″) slit. An echelle spectrograph with these properties is the perfect opportunity for Gemini to enable science that cannot currently be done anywhere else in the world.

Dwarf galaxies are the most common type of galaxy and are the local analogs of the Dark Matter Mini-Halos proposed in ΛCDM as the building blocks of larger galaxies in the early universe. Yet, even the basic structure of dwarf irregular (dIm) galaxies remains controversial. Studies of the distributions of projected minor-to-major axis ratios b/a have been interpreted to mean that dIm galaxies are thick disks with intrinsic ratios $(b/a)_0$ 1.5–3 times that of spirals (Hodge & Hitchcock 1966; van den Berg 1988; Staveley-Smith et al. 1992). Yet others have interpreted the distribution as evidence that dIm galaxies are triaxial (Binggeli & Popescu 1995), only a little less spherical than dwarf ellipticals (Sung et al. 1998). Clearly, statistical analysis of axis ratios have not been adequate to define the true shapes of dIm galaxies.

Fortunately, the *stellar* kinematics of an individual galaxy indicates its intrinsic shape. The ratio V/σ_z is an indicator of how kinematically hot a system is, and, therefore, its structure. Here V is the maximum speed of rotation of the galaxy. Elliptical and dEs have $V/\sigma_z < 1$ (Figure 4-6 in Binney & Tremaine 1987; Pedraz et al. 2002) while spirals have $V/\sigma_z > 1$, usually 2–5 (Bottema 1993, Vega Beltrán et al. 2001). The stellar velocity *dispersion* to date has been measured in only a few Im galaxies (a few more are in progress, Jackson PhD thesis in progress): NGC 2552 (Swaters 1999), LMC (van der Marel et al. 2002), and NGC 4449 (Hunter et al. 2005; see Figure 1). The ratio V/σ_z is 3–5 in these galaxies, consistent with a flattened disk and contrary to the b/a studies. However, these systems are at the high luminosity end of the distribution of dwarfs ($M_V \sim -17.3$ to -18.6). Does the shape change as one moves further from the spiral–dwarf transition? Lee (2007) has shown that there is a change in the star formation histories of dwarf galaxies at an absolute magnitude M_B of -15 with lower luminosity systems being more bursty. Is this accompanied by a change in the shape of the galaxies?

With stellar kinematic data, we are also able to determine the mass of the disk and reexamine the amount and distribution of dark matter in dwarfs. The data now available suggest that the fraction of dark matter varies widely—from very high to insignificant in dIm galaxies (Côté et al. 2000). These results are from HI rotation curves, but the contribution of the stellar disk is problematical because of unknown star formation histories and possible variations in the low mass stellar population. Stellar masses are often determined only by assuming the "maximum disk" mass, a disk that predicts the highest velocities that do not exceed the inner rotation curve. The "maximum disk" also gives the minimum dark matter mass. However, in normal dIm galaxies, dark matter is important even in the inner parts (de Blok & McGaugh 1997, Côté et al. 2000), so "maximum disk" models could underestimate dark matter. But studies of several dwarfs suggest that they may contain no dark matter under the maximum-disk assumption (for example, Swaters 1999). Determining realistic estimates of the dark matter content of dwarfs is an important input to ΛCMD models of the universe.

PhD student Megan Jackson, Dr. Vera Rubin, and I have used the Echelle on the KPNO 4 m in order to measure the stellar velocity dispersions, as well as rotation velocities, in several brighter dwarfs. We transformed the Echelle into a long-slit spectrograph by replacing the cross-disperser with a flat mirror and inserting a pre-slit filter to isolate our wavelength range (the MgIb absorption lines around 5170 Å). This allowed us to integrate along the slit to increase signal-to-noise. We also opened the slit to a width of $2.5''$ to increase the throughput while still retaining sufficient spectral resolution. These two things—a long slit and a wide slit—are essential in this severely photon-starved regime. For example, to measure the stellar velocity dispersion in NGC 4449, a very bright Im galaxy, we summed in $24''$ steps along the slit. Furthermore, the long slit increases our efficiency by giving us simultaneous measurements at multiple points along the slit.

Other spectrographs around the world that have a long slit have low spectral resolution, and those with the spectral resolution we need use fibers, which lose light, or small narrow slits, which don't collect enough light. (One can quickly turn an 8 m telescope into the equivalent of a 2 m for this science without a well-designed instrument). Integral Field Units lose on both of these counts since they usually use fibers with small diameters (compared to $24''\times2.5''$), and so they do not gather enough photons in each position, nor do they have the contiguous, complete spatial coverage that would allow spatial averaging.

Thus, to push on to fainter, more typical dwarfs we need a big telescope ($\geq$6 meters). And we need a *long*-slit echelle spectrograph that can achieve a resolution of R$\sim$20,000 at

5170 Å with a *wide* (2-4″) slit. The resolution is dictated by the fact that dwarfs do not rotate very fast and have low velocity dispersions. A slit length of 5′ would be best; a slit length of 3′ would be acceptable. The slit must also be rotatable to a particular angle on the sky, and the free spectral range of one order, isolated with a filter and the cross-disperser replaced with a flat mirror, should be of order 100 Å. A high-throughput echelle spectrograph with these properties on Gemini would enable science that cannot currently be done anywhere else in the world.

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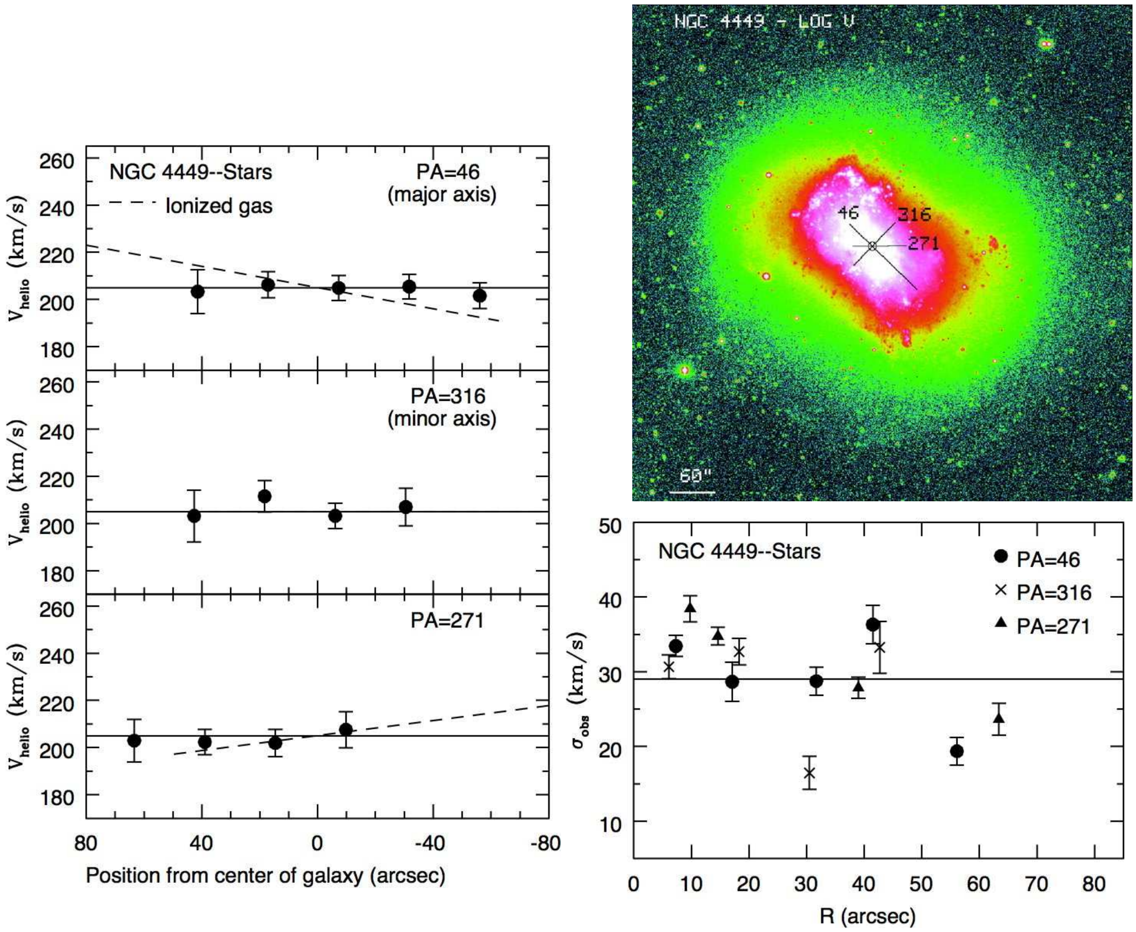

Figure 1: Radial velocities and stellar velocity dispersions measured from each spectrum of NGC 4449 taken with the KPNO 4-m Echelle spectrograph, summed in steps of 24″ along the slit (slit width 2.5″). The dashed lines are the rotation velocities determined from the ionized gas. The velocity dispersion of the stars was measured to be 29±2 km/s. We confirmed the lack of rotation in the stars, even though the gas does exhibit rotation. If we assume that the stars are in a disk seen face-on and use the maximum rotation speed from the model determined from the gas kinematics (Hunter et al. 2002), then V/σ_z measured globally is 3, indicating a kinematically relatively cold thin disk. From Hunter et al. (2005).