CUNY Masters Thesis Proposal: Mapping Motions in the Nearest Galaxies

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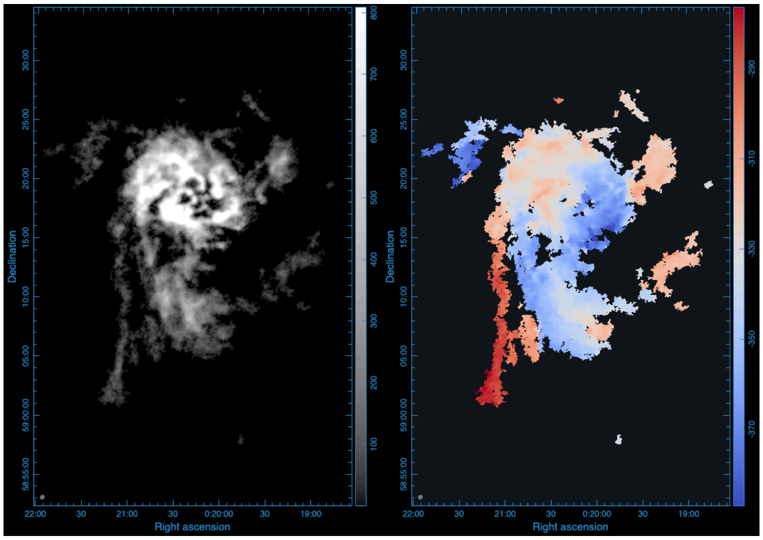
Motivation: Galaxies reside at the intersection of rich subfields of astrophysics. They are bound together by dark matter, which sets a galaxy's overall gravitational potential, which in turn shapes the motions and distribution of the galaxy's gas and stars. The location and motion of gas is thus an excellent probe of the distribution of dark matter within the galaxy. In addition, the gas is also tightly coupled to stars, which are continuously born from the gas, and which then disrupt the gas as the stars evolve, lose mass, and eventually explode in supernova ("stellar feedback). This connection makes the small-scale motion & distribution of the gas a useful tool for understanding how stars affect gas. These ingredients – the structure of dark matter and the nature of stellar feedback – are critical for understanding galaxy evolution at all redshifts, but can best be studied in the very nearest galaxies, where we have the highest resolution view of the gas and stars.

The "Local Group L-Band Survey" (LGLBS) is a new, state of the art study of the gas in the very nearest star forming galaxies – Andromeda (M31), M33, NGC 6822, IC1613, WLM, and IC10. This project has used the Karl Jansky Very Large Array (VLA) to map all 6 of these galaxies with the highest possible spatial and spectral resolution, covering a region of the radio spectrum that is sensitive to the 21 cm line transition of atomic hydrogen (HI, pronounced "H-one") that is ubiquitous in galaxies. Julianne Dalcanton is one of the Co-PI's of the project, and Eric Koch has led all the data reduction for mapping the atomic hydrogen, which has produced a large number of "data cubes" that contain spectra of the gas at every position in these galaxies. Because of the doppler redshift, the 21cm line shifts in wavelength (or equivalently, frequency) when the atomic gas is moving towards us or away from us. This makes the LGLBS data cubes ideal for studying gas motions. In particular, the incredible resolution of the data should allow us to make fundamentally new measurements of the detailed behavior of the gas.



New HI observations of the dwarf galaxy IC10 from LGLBS that resolve fine-scale velocity structure of the gas, motivating the proposed thesis work. Left: HI column density. Right: HI centroid velocity

Project: The project includes two possible phases, which can be done in any order. In Option A, the thesis student will apply standard software that models the motions of the galaxy as a series of rotating, circular rings that are allowed to “tilt” with respect to the observer. These “tilted ring models” are good first tools for characterizing the large scale motions of the gas, and can be used to derive “rotation curves” (i.e., how fast the galaxy is rotating as a function of radius), which have long been used to characterize the underlying dark matter distribution. Rotation curves have been calculated previously for these galaxies (see this detailed paper on NGC 6822, for example), but the high velocity resolution of the new data will better show departures from the mean motion, which can help diagnose internal gas flows and possible departures from equilibrium. This first phase can result in a paper that describes the new rotation curve measurements, shows the departures from simple models, and potentially fits the dark matter potential. Some overview slides of tilted ring modeling can be found here and here, and a slide deck with an overview of rotation curves derived from tilted ring modeling can be found here.

In Option B, the thesis student will develop new fitting tools that move beyond the tilted ring model, and that are better suited to the very complex motions that the new LGLBS data have revealed. Working with David Hogg (a world expert in fitting models to complex data), and Julianne Dalcanton & Eric Koch, the student will adapt and expand upon the work in Braun 1991 to model the galaxy motions as connected segments of cylinders, rather than axisymmetric rings. This will allow far more flexibility in the model, allowing it to handle the complexity revealed in the new high-resolution model. This tool is desperately needed to characterize the small-scale motions in the gas, which can then be connected with our knowledge of the evolving stars. This part of the project will involve learning about modern fitting tools and developing software skills. There are multiple paper possibilities including: (1) a paper describing the new tool; and (2) a paper describing the resulting fits to the LGLBS data. The resulting fits will also make it possible to measure the velocity dispersion of the gas, which would lead the student to be a co-author on subsequent analysis papers.

We note that:

1. A student who is interested in developing fitting tools and building software skills can jump straight to Option B, which is more novel and breaks new ground. Option B also does not immediately require as much knowledge of astrophysics, so can be started before much coursework has been completed.
2. The LGLBS collaboration has faculty-level Co-PIs at University of Wisconsin, Ohio State University, Michigan State, University of Alberta, and the Max Planck Institüt fur Astronomie in Heidelberg, so there are multiple opportunities for a student to continue working on the project in graduate school, if they are interested.

Example of cylindrical model segment from Braun 1991:

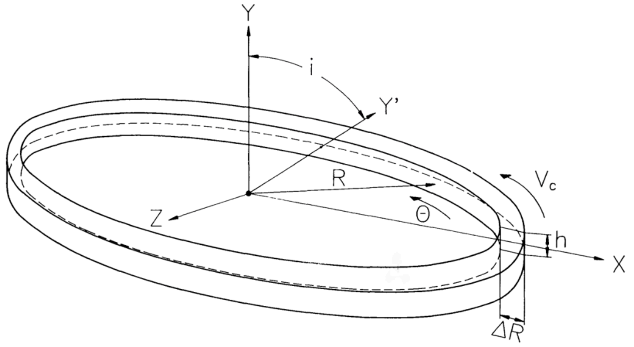


FIG. 1.—Illustration of the geometry used to define the quantities in eqs. (1) and (3). The (X, Y)-plane is the plane of the sky, with the observer looking along the Z-axis. The (X, Y')-plane is the plane of the galaxy, which is tilted by an inclination angle i away from the plane of the sky. The azimuth angle within the plane of the galaxy is given by θ. Each spiral arm segment is interpreted as a portion in azimuth of a rotating cylinder with thickness ΔR and height h at a radius R and rotation velocity V_c.

Which can be compared to the standard, more restricted tilted ring model: