Modeling Spiral Galaxy Luminosity Profiles

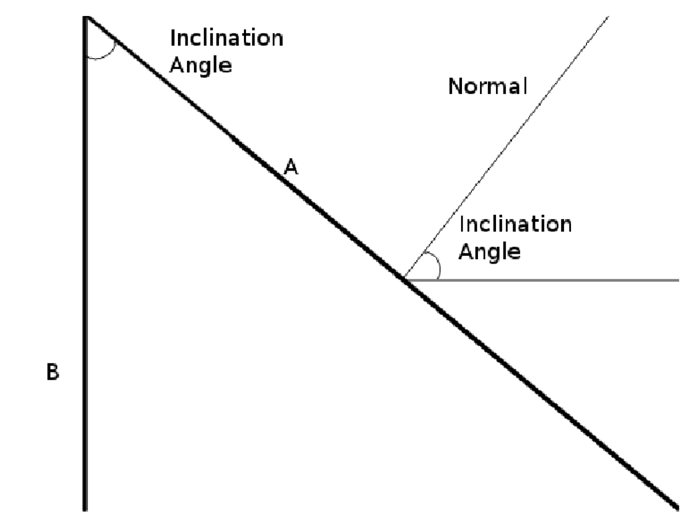
Jordan Rozum[1], **Matt Garlock**[2], **Shane L. Larson**[1], **& Bradley W. Carroll**[2]

[1]Department of Physics, Utah State University
[2]Department of Physics, Weber State University

The distribution of spiral and bar galaxy inclination angles is expected to be uniform. However, analysis of several major galaxy catalogs shows this is not the case; galaxies oriented near edge-on are significantly more common in these catalogs. In an attempt to explain this discrepancy, we have developed a galaxy simulation code to compute the appearance of a spiral type galaxy as a function of its morphological parameters. We examine the dependence of observed brightness upon inclination angle by using smooth luminous mass density and interstellar medium (ISM) density distributions. The luminous mass component is integrated along a particular line of sight, thus producing a mass distribution, from which a surface luminosity profile is derived. The ISM component is integrated alongside the luminous mass component to account for light extinction. If the dependence of the total surface brightness on inclination strongly corresponds to the observed distribution of inclination angles, we can attribute much of the discrepancy to a geometrical selection effect.

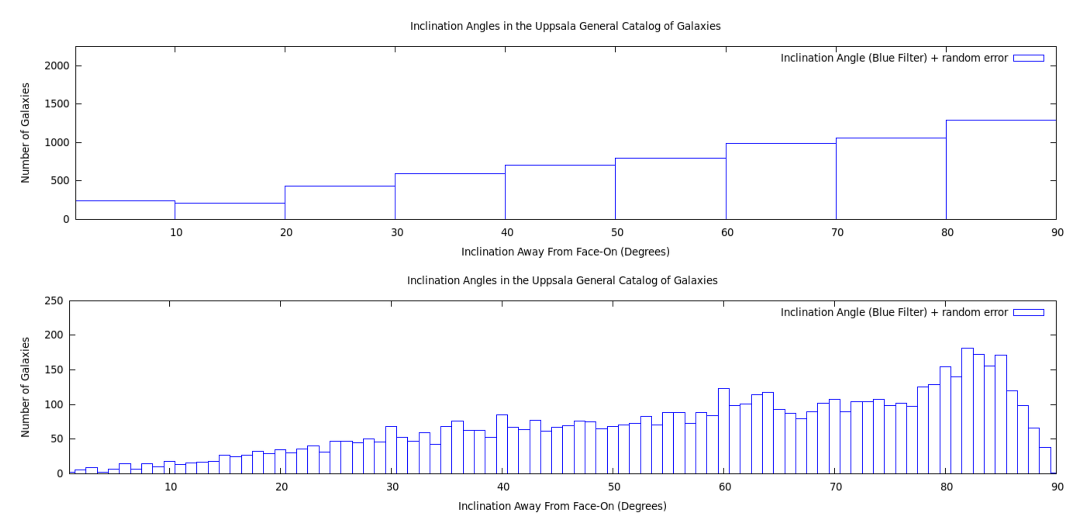
Motivation: Galaxy Inclination

Large galaxy surveys catalog the morphological properties of galaxies. Particularly, the observed axis ratio is often reported, which can be used to determine a spiral galaxy's inclination relative to Earth.



From this diagram, we can see that the inclination angle is given by the arccosine of the axis ratio, assuming a perfectly flat galaxy.

When the inclinations obtained from the axis ratios of galaxies designated as spirals or barred spirals are plotted in a histogram, an uneven distribution is observed: [1].



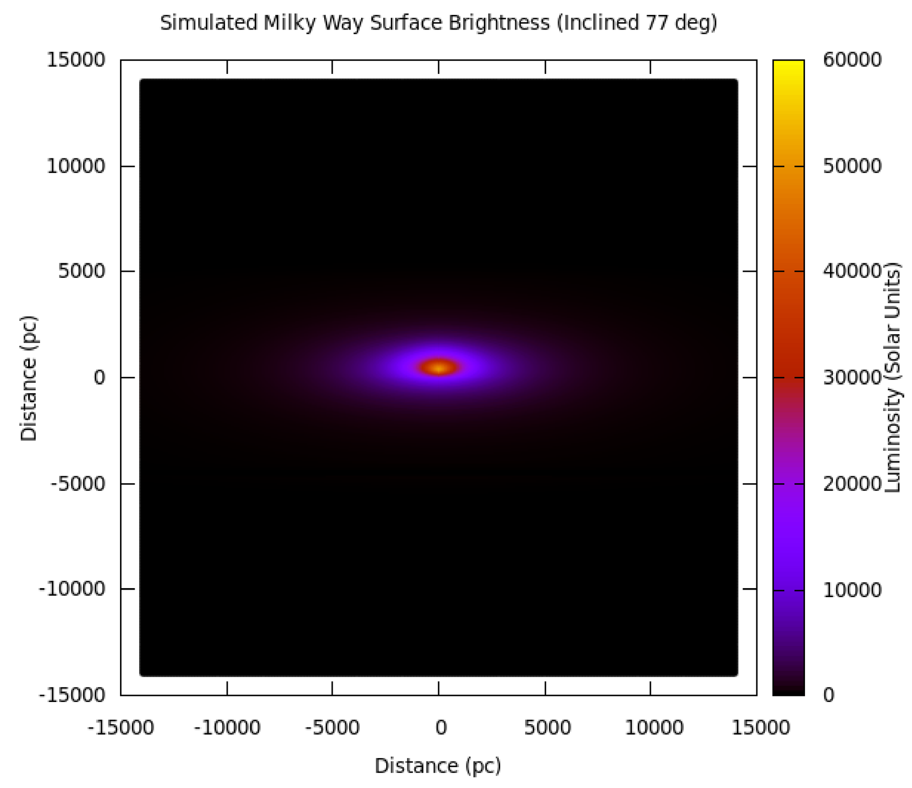
We can see more cataloged galaxies are positioned near edge-on. The cause of this inhomogeneity is unknown. It is possible that it is due in part to a geometrically related observational effect. Specifically, the orientation of a spiral galaxy has an effect on the amount of starlight that is transmitted to Earth, or blocked by other stars. However, if more light is blocked, there is a higher concentration of stars per area on the sky, which corresponds to a greater observed intensity. The finite thickness of galaxies contributes to the decrease in the observed number of galaxies at high inclinations in the histogram with smaller bins. Analyzing the difference between these distributions should provide clues about the typical thickness of spiral galaxies.

Mass Distribution Model

To analyze how the geometry of galaxies affects their detectability, we derive a surface luminosity profile from Dehnen and Binney's 1998 galactic density distribution [2]. A fine grid of pixels is established, and for each pixel, a coordinate transformation is performed that accounts for inclination. To obtain the mass contained in each pixel, the line integral of the density distribution is numerically computed along the line of sight, through the pixel. Each pixel mass is then converted to a luminosity via the process outlined in the next section. This luminosity is then decreased as a function of the mass of the dust in front of each pixel:

$$L = L_0 \cdot \exp\left(\int \kappa_\nu \rho_{ISM} ds\right)$$

Where κ_ν is the mass attenuation coefficient.
Here is an example result of this process:



The galaxy shown here was generated using parameters from Dehnen and Binney's standard model galaxy, which was used as an approximation to the Milky Way. Because the model treats the galaxy as cylindrically symmetric, no spirals arms are seen here.

Converting Mass to Luminosity

To convert a given pixel mass to luminosity, we begin with a modified version of the Salpeter Initial Mass Function due to Baldry and Glazebrook (2003) [3]:

$$\frac{dn}{d\log(m)} \propto m^{-\Gamma}$$

where

$$\Gamma = \begin{cases} 0.5 & 0.1M_\odot \leq m \leq 0.5M_\odot \\ 1.15 & 0.5M_\odot \leq m \leq 120M_\odot \end{cases}$$

This gives the fraction of stars within any given mass range. We then evolve the population by removing stars whose lifetime is shorter than the mean age of the galactic disk. Then, using well-known mass-luminosity relationships for main sequence stars, we find the bolometric luminosity for each star. Applying a bolometric correction and integrating gives the total V-Band luminosity for each pixel.

References

[1] UGC Galactic Catalog, NASA HEASARC Archive, `http://heasarc.gsfc.nasa.gov/docs/archive.html`.

[2] W. Dehnen & J. Binney, 1998, MNRAS, **294**, 429

[3] I. K. Baldry & K. Glazebrook, 2003, ApJ, **593**, 258

[4] NASA HST Image No. heic0710a, `http://www.spacetelescope.org/images/heic0710a/`.

[5] A. Block. Mount Lemon Sky Center, University of Arizona, `http://skycenter.arizona.edu/gallery/Galaxies/NGC891`.

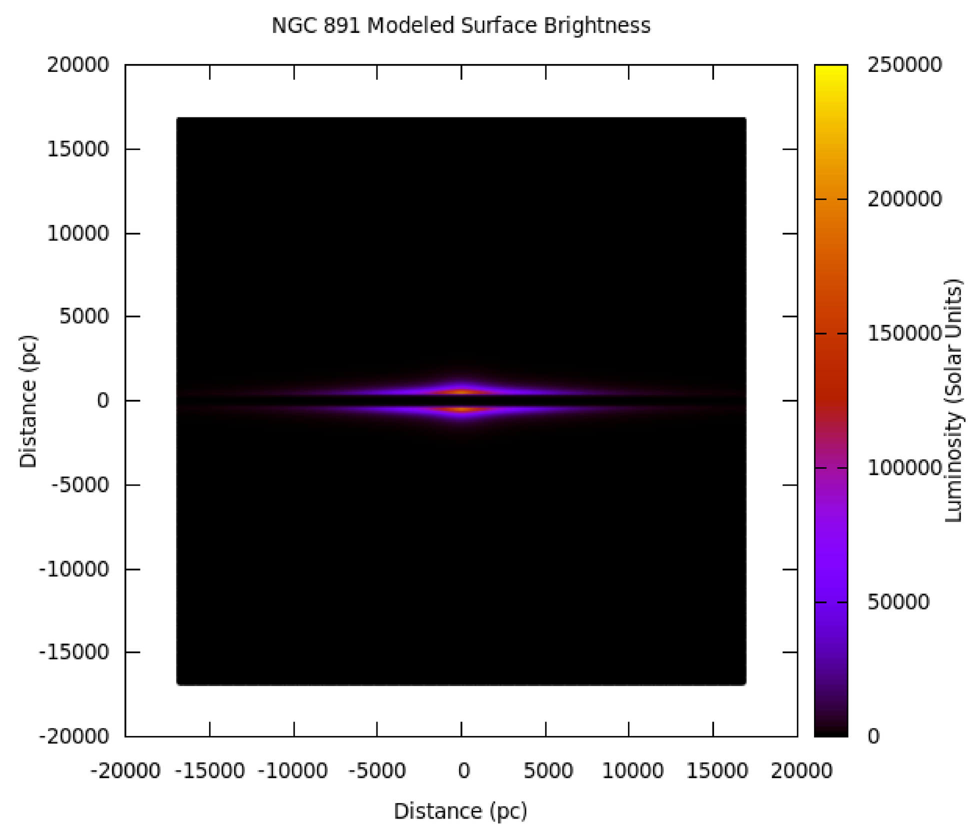
[6] Xilouris et al. 1998, A&A, **331**, 894.

[7] Aoki et al. 1991, PASJ, **43**, 755.

Validation

The total mass of the galaxy should not depend on inclination, and we use this fact to test the accuracy of our numerical methods The largest difference between masses is on the order of 0.5%. To evaluate the validity of the modeled structure, we compare generated surface brightness profiles to real images of galaxies, as we do below with NGC 891:

Image from Block (2008) [5]

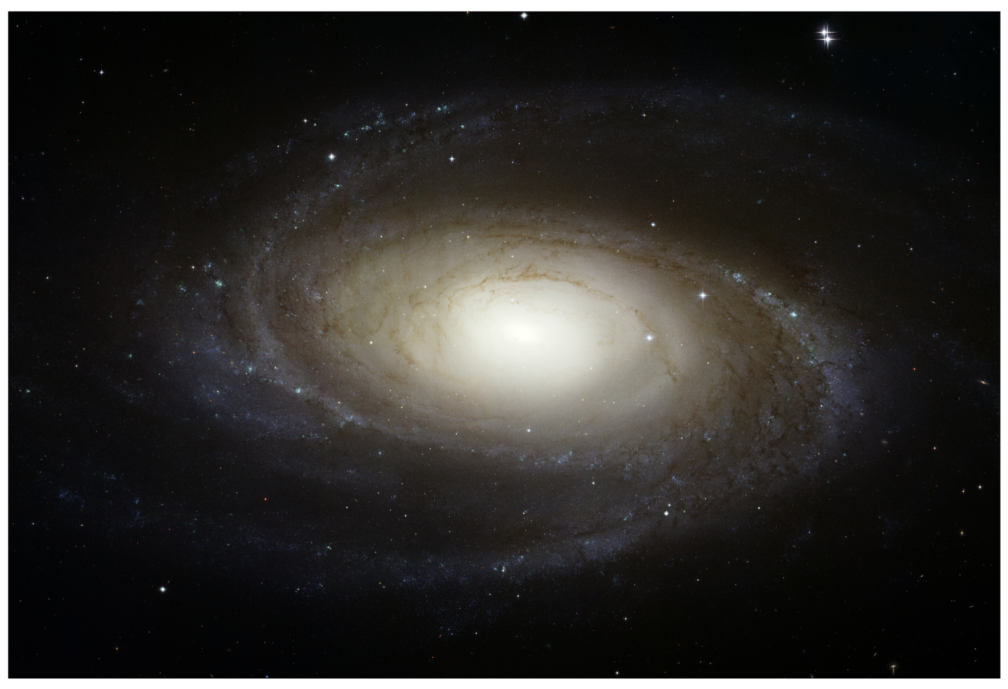


Parameters for this Profile from Aoki et al. (1991) [7] and Xilouris et al. (1998) [6]

The overall structure is captured in the simulation: the thin bulge can be seen in both images, as can the darker dust lanes through the center. We are currently in the process of normalizing the V-band magnitudes to those in observed galaxies. The iconic fillamentary structure of NGC 891 and the faint glow seen outside the main disk are not accounted for by this current model.

Summary and Future Work

Fitting the Model - By varying input parameters for the extinguishing function, we will attempt to closely match the observed inclination distributions using a large number of galaxies with randomly varying parameters. We will determine what distributions of disk thicknesses and radial scale-heights are capable of producing the observed decreases in number of observed galaxies with small axis ratios.



Summary - We have developed a model for the surface brightness of spiral galaxies using as inputs morphological and structural parameters. The luminosity profiles are derived from density distributions and principles of stellar populations. We are able to reproduce the overall structure of individual galaxies, and are currently working to normalize the intensities to observed galaxy populations. Our next step is to apply this model in investigating uneven inclination distributions in major galaxy catalogs.