# Modeling Spiral Galaxy Surface Luminosity to Explain Non-Uniform Inclination Distributions

**Jordan Rozum**[1] **and Shane L. Larson**[2]

[1] Department of Physics, Utah State University

[2] Department of Physics, Northwestern University

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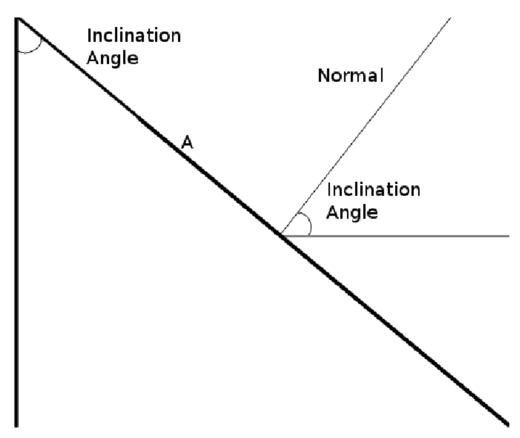
*The distribution of spiral and bar galaxy inclination angles is expected to be uniform. However, analysis of several major galaxy catalogs shows this is not the case; galaxies oriented near edge-on are significantly more common in these catalogs. In an attempt to explain this discrepancy, we have developed 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 ISM density distributions. The luminous 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 component to account for light extinction. Preliminary data ignoring extinction demonstrate trends matching the observed small inclination distribution. We reproduce overall spiral galaxy morphology and outline the ongoing validation process.*

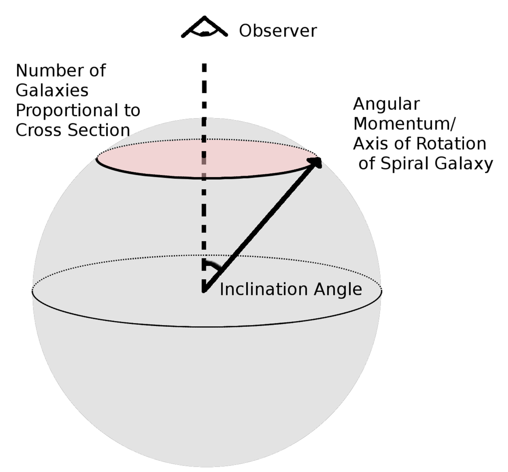
## Motivation: Galaxy Inclination

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.

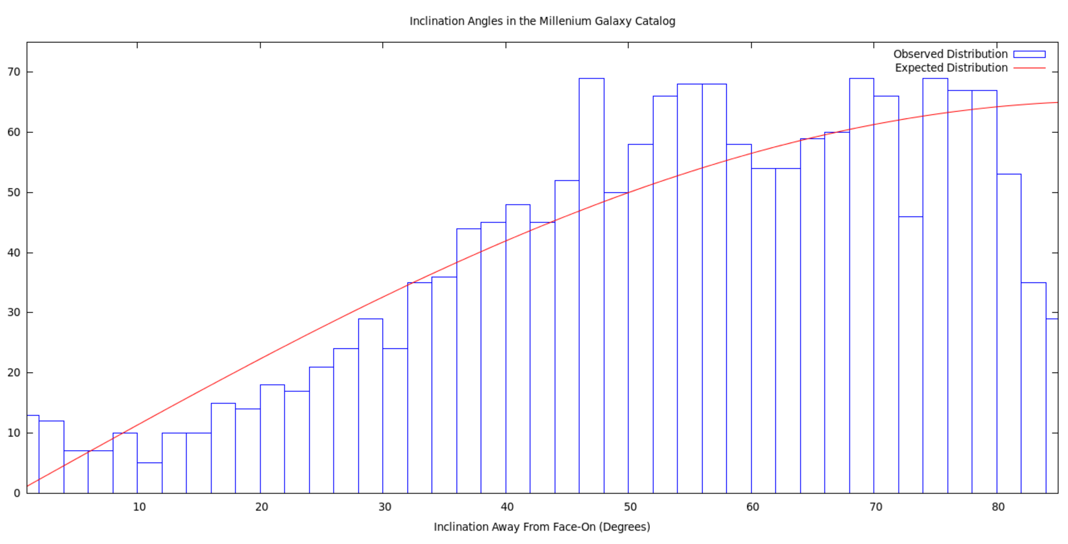



From this diagram, we can see that the inclination angle of a flat galaxy is given by the arccosine of the axis ratio.

The number of spiral galaxies with a certain inclination angle should be proportional to the sine of the inclination angle, assuming uniform distribution of spiral galaxy angular momentum. This can be derived using the following diagram:




There are discrepancies between the expected inclination distribution and some, but not all, galaxy catalog inclination distributions. Below, the MGC catalog shows some slight variation from the expected distribution:




Spiral and barred spiral galaxy inclination distribution in MGC [1].

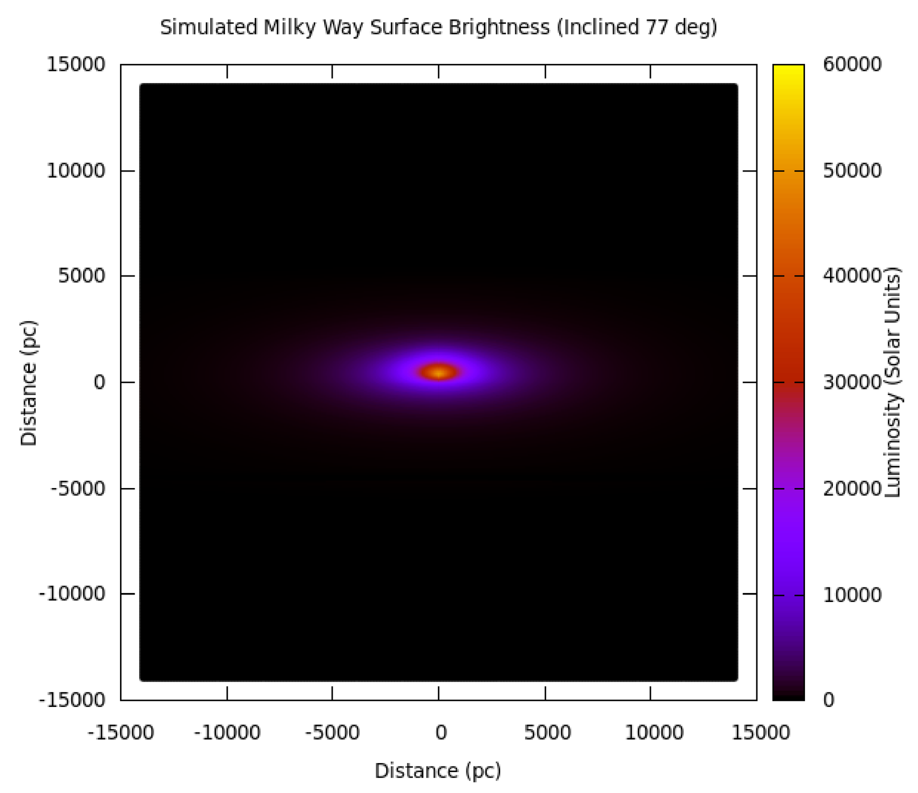
These variations could be attributed to light extinction by dust and the concentration of stars per pixel on a detector, which both depend on inclination. They could also be attributed to misclassification of galaxies; elliptical galaxies look like inclined spirals at low resolution and so an erroneous inclination might be recorded. Therefore, brightness and inclination can tell us about galaxy misclassification.

## 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 $\kappa_\nu$ 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

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

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] Millennium Galaxy Catalogue, J. Liske et al., `https://www.eso.org/~jliske/mgc/`.

[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`.

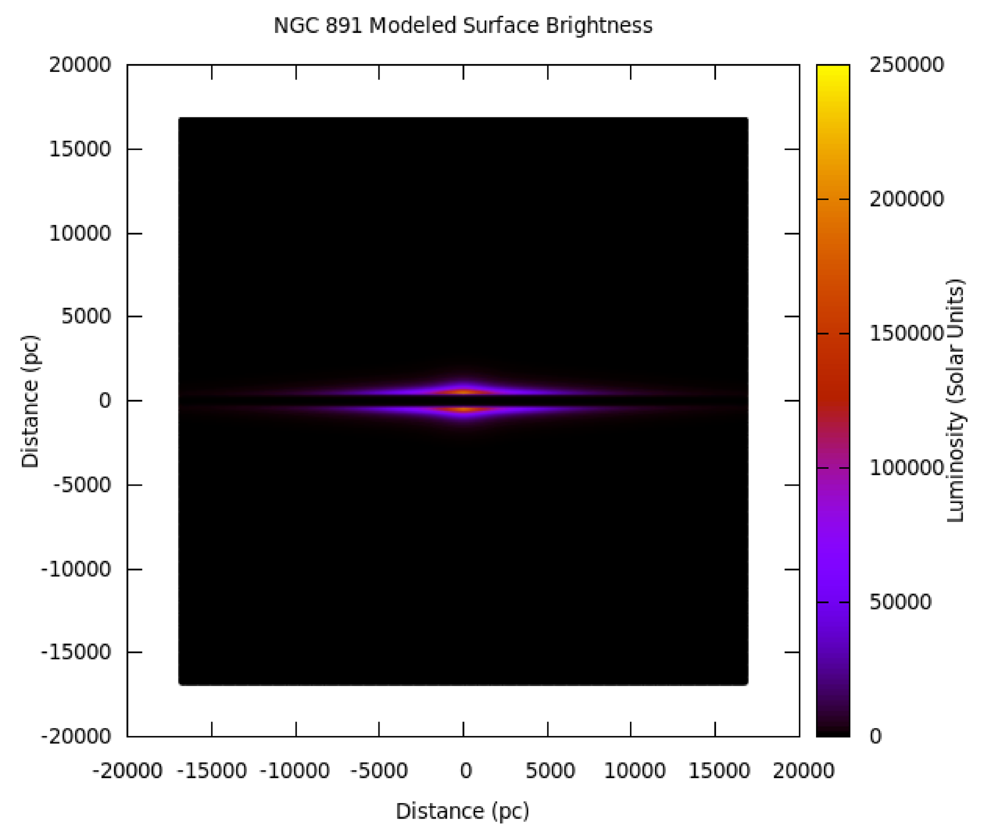
[6] Xilouris et al. 1998, A&A, **331**, 894.

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

## Results to Date and 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:

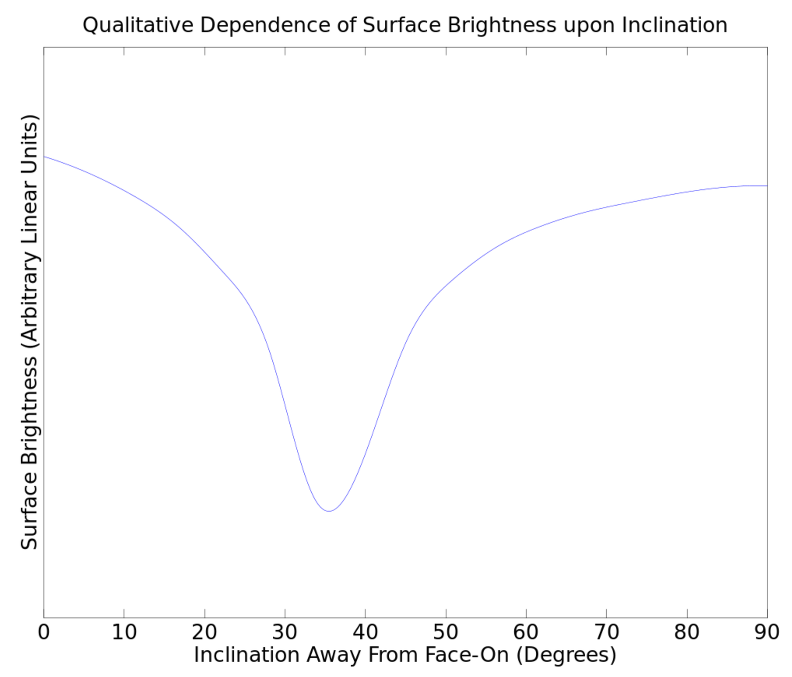
Image from Block (2008) [5]




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. Due to large uncertainty in some of the input parameters, the total luminosity is only valid to an order of magnitude.

By generating a typical galaxy and removing regions below a certain brightness threshhold, we can estimate a detected brightness. In practice, this threshhold would depend upon the nature of the optics used, so we have chosen arbitrary detection cutoffs and telescope resolution to illustrate the qualitative result below:




Since we do not yet know the exact position or depth of the minimum, we cannot say whether the geometrical effect here is significant enough to appreciably alter the observed inclination distributions.

## 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 currently working to normalize the intensities to observed galaxy populations by accounting for instrument effects in the code.
- The ultimate goal is to apply this model in investigating variations in inclination distributions in major galaxy catalogs, with particular emphasis on possible galaxy morphology misclassification.