Testing the Modal Density Wave Theory in Disk Galaxies: The Effect of Diskmass Density on Spiral Arm Pitch Angle. R.A. Flatman, B.L. Davis, D. Kennefick, D.W. Shields, Arkansas Galaxy Evolution Survey, University of Arkansas.

Introduction: The details concerning the formation of spiral arms are still unknown and the focus of this work is to propose a relationship between the spirality of the arms and the concentration of mass in the bulge and disk of the galaxy. For the purposes of this work, spirality is a measure of how tightly or loosely wound the arms are around the bulge, determined by the pitch angle between the arms and a bisecting circle, using the assumption that the arms form a logarithmic spiral as shown in Figure 1.

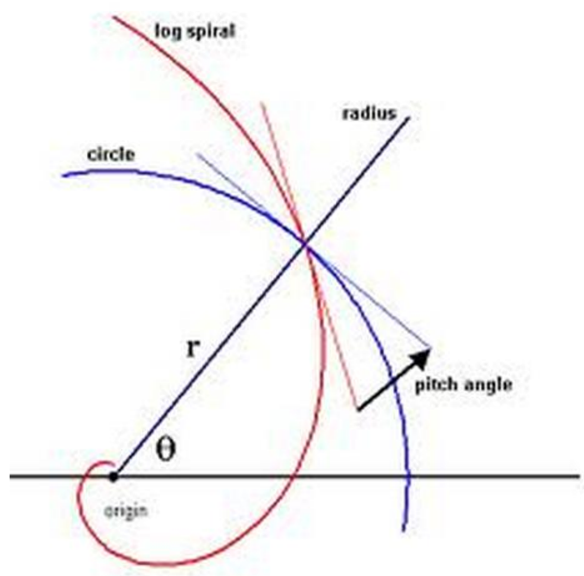

FIG 1. Pitch angle decomposition by constructing a circle (blue) intersecting a logarithmic spiral (red) at some radius r. If lines are drawn tangent to the circle and the spiral at the intersecting point, than the pitch angle is the angle between the two tangent lines. A circle would have a pitch angle of 0 degrees and a radial line would have a pitch angle of 180 degrees.

The current general consensus is that spiral arms are formed by density waves that stars traverse through rather than being composed of stars and matter themselves. Evidence for this theory can be seen by the fact that disk galaxies maintain the same spirality over time, that is, the arms do not wind up as they would from differential rotation caused by stars in the arms rotating at different rates. Hubble found that the spirality is related to the bulge mass of the galaxy, with tightly wound spirals containing larger and brighter bulges and the opposite for loosely wound spirals. This work plans to extend this theory by adding another parameter to this relationship, the diskmass. The idea is that the mass in the disk is significant enough to affect the shape and formation of spiral arms by Equation 1, with φ as the pitch angle, M as the total mass in the bulge and σ as the mass density of the disk of the galaxy.

$$\tan\varphi \propto \frac{\sigma}{M} \quad (1)$$

Fast Fourier analysis of pitch angles and results: In order to test this theory, the diskmass and pitch angles for selected galaxies must be obtained. Diskmasses will be obtained from The Diskmass Survey by Bershady and associates [1], and will be available when published. The pitch angles are measured from a process developed by Davis [2]. Face on images of disk galaxies [3] are sent through a Fast Fourier transformation for various modes, spiral symmetries, and pitch angles. Then the data is analyzed to find the most stable mode and largest pitch angle amplitude from the Fourier analysis, an example is given in Figure 2. If no face on view is available then the images are projected onto a face on view. A circular projection is developed from an elliptical shape by rotating the object until it is upright and magnifying the semi minor axis to match the same dimensions as the longer one. This allows a Fast Fourier transformation to be done on the effective face-on view of that galaxy.

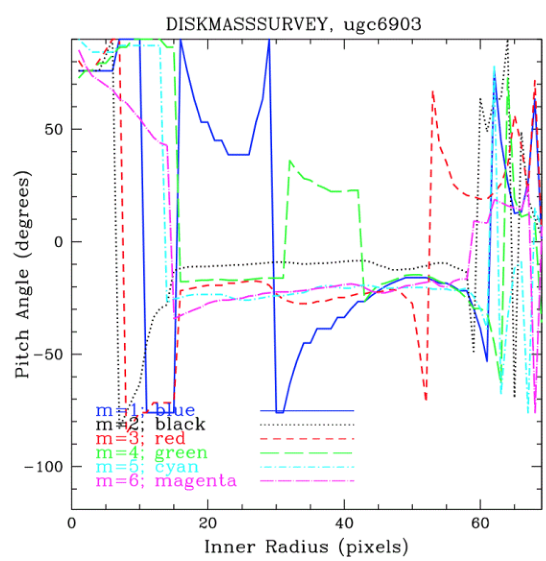

FIG 2. Results of Fast Fourier transformation of a single galaxy, UGC6903 for various modes and pitch angles. For a perfectly logarithmic spiral, all the modes should converge to same value of pitch angle. For this galaxy, it can be seen that the most prominent mode is 2, which gives a pitch angle of -10.19 degrees and a standard deviation of 2.02 degrees.

Pitch angles have been measured for selected galaxies from The Diskmass Survey and have been collected in Figure 3. Galaxies were selected based on the following characteristics: 1) Galaxies were of type Sa, Sb, Sc. 2) Mass data availability from the Diskmass Survey. 3) Galaxies were primarily face-on view. 4) Galaxies had, at most, pitch angles of ~50 degrees. 5) Clear images of the galaxies were available in fits format for compatibility with software tools.

GALAXY (UGC)	PITCH ANGLE (deg)	Error (+/- deg)	Mode
74	27.75	7.36	3
463	31.47	4.39	4
1087	12.22	8.36	2
1908	39.43	3.72	4
3140	-14.79	6.80	3
3997	-24.12	5.99	6
4036	-48.46	5.73	6
4107	-19.95	7.82	4
4189	-25.78	6.06	3
4256	32.46	13.49	2
4368	12.07	3.56	2
4380	-21.50	6.24	3
4458	-25.16	6.00	6
4622	-29.30	10.95	6
5180	27.34	6.38	6
6077	-50.34	9.90	5
6693	-35.28	11.66	3
6903	-10.19	2.03	2
7244	23.25	7.40	4
7416	-26.67	4.09	3
7917	-25.83	6.14	6
8196	-13.73	2.19	5
8320	-28.57	10.34	4
9177	-17.60	3.81	4
9837	35.33	13.93	5
9965	-24.31	7.11	5
10269	22.48	10.82	5
11318	-31.16	4.05	3
12391	-31.23	12.95	4
12702	-30.47	10.22	4

FIG 3. Tabulated values of pitch angles for selected galaxies in The Diskmass Survey. These galaxies are from the UGC classification. Pitch angles vary from 10.91 to 50.34 degrees with a mean of 26.60 degrees and a standard deviation of 9.60 degrees. Mode represents the amount of symmetry in a galaxy's spiral arms. (e.g. a mode of 3 signifies a 3 armed spiral with the arms branching out at 120 degree symmetry from each other.)

Conclusions of results & further research: At this time results are inconclusive as to the relationship in Equation 1, as this is only a partial completion until the data from the diskmass survey comes in. The pitch angle data is helpful however as it gives us an idea of how accurate our methods of finding the pitch angles are and how to make them better. Galaxies of different modes and pitch angles can be constructed geometrically on paper and then can be compared with the actual images themselves to determine the accuracy of Fourier analysis used to determine the pitch angles. If the image is clear and without blemish, the algorithm does a good job at detecting pitch angles for anything under 50 degrees. However an occasional nearby star in the foreground or background of the galaxy image can cause a disruption in the data, as in the fourth mode in Figure 2. Since the pitch angle algorithm has been shown reliable, the next step would be to find a planar correlation between pitch angle, diskmass density, and the bulge mass of galaxies using the data from The Diskmass Survey.

Acknowledgments: This study is supported by the National Science Foundation (grant #1157002)

References: [1] M.A. Bershady et al. (2010) APJ, 716, 198-233. [2] B.L. Davis et al. (2012), APJS, 199, 33.[3] The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.