Investigating the Mass-Pitch Angle Relationship in Active Spiral Galaxies at Intermediate Redshift

B. M. Watson[1], R. S. Barrows[2], J. A. Hughes[2], J. D. Kennefick[2,3]
[1]Department of Physics and Astronomy, 108 Lewis Hall, University of Mississippi, Post Office Box 1848, University, MS, 38677; [2]Arkansas Center for Space and Planetary Science, University of Arkansas, FELD 202, Fayetteville, AR 72701; [3]Physics Department, University of Arkansas, 825 W. Dickson St., Fayetteville, AR 72701

Introduction: The Arkansas Galaxy Evolution Survey (AGES) seeks to understand the growth of the early universe by analyzing galactic evolution over time. In Seigar et al. 2008[1], AGES collaborators discovered a correlation between galactic central black hole masses and the pitch angles of spiral arms in local, quiescent, disk galaxies. This mass-pitch angle correlation provides a method for estimating black hole masses purely through image reduction and analysis. If extended to more distant galaxies of varying classifications and thoroughly validated, the correlation could be useful in studying the evolution of galaxies that were not previously measurable.

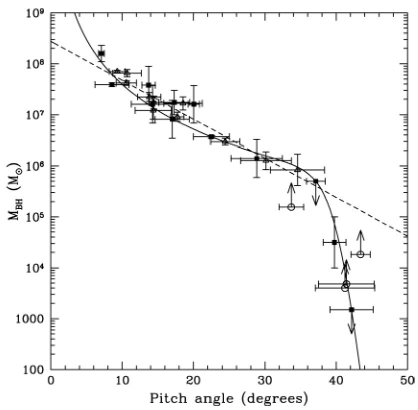

Figure 1: Mass - Pitch Angle Correlation from Seigar et al. 2008

Active galaxies are those which contain at their centers active galactic nuclei. Active galactic nuclei (AGN) are so named because their galactic central supermassive black holes are accreting matter at such a rate that highly luminous radiation is emitted by the accretion disks. Among the most luminous AGN's are quasars, which are highly emissive, distant objects at relatively high redshift. Due to their extreme luminosities, quasars can be observed at far greater distances than can quiescent galaxies. Spectral emissions from such distant quasars can be analyzed to provide insight into the physical properties of the quasars.

In this study, quasars of intermediate redshift in disk galaxies exhibiting spiral structure were analyzed to explore the possible correlation between morphological features of the galactic disks and the masses of the galactic central supermassive black holes. In so doing, a sample of quasars at intermediate redshift was drawn from the Sloan Digital Sky Survey (SDSS), whereupon those galaxies exhibiting visible spiral structure were selected for analysis. Each galaxy's spiral arm pitch angle was measured utilizing a two dimensional fast fourier transform (2DFFT) code, then plotted against its supermassive black hole mass. The statistical relationship between the two features was then evaluated.

Data Sample: For the purposes of this study, Data Release 7 (DR7) of the SDSS was utilized. Upon filtering the DR7 data for quasars with strong broad line regions at intermediate redshifts, an initial sample of 4,124 galaxies was selected.[2] From this sample, each galaxy was visually inspected for evidence of observable spiral structure. Following the visual inspection, a subset of 75 galaxies was selected for analysis, with redshifts ranging from z = 0.06 through z = 0.4.

For each of the 75 galaxies that were selected, filtered images in flexible image transport system (FITS) format were downloaded from the SDSS DR7 database, to be analyzed via the Image Reduction and Analysis Facility (IRAF) and DS9 graphical interface softwares. For each galaxy in this sample, the r filter was chosen for pitch angle evaluation, corresponding to a central wavelength of 6165Å. This image filter provided the most sharply defined morphological structure across the range of redshifts being observed.

For each image in the sample, the IRAF ELLIPSE task was utilized to determine the inclination and position angles of the galaxies. Utilizing the ROTATE and MAGNIFY tasks within IRAF, each galaxy was deprojected to a face-on configuration for the purpose of pitch angle measurement. Following deprojection, each galaxy's pitch angle was measured as a function of the galactic disk's inner radius using a proprietary 2DFFT routine coded by AGES members[3]. For detailed explanation of the

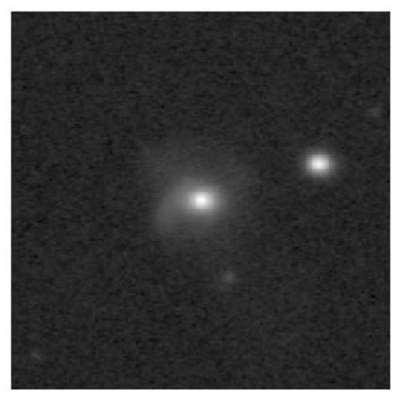

Figure 2: Deprojected galaxy at z = 0.0645

deprojection and pitch angle measurement procedures, consult Davis et al. 2012.

Supermassive black hole mass estimates were provided by the SDSS DR7 quasar catalogue.[4] The spectral mass estimates therein were calculated using the scaling relationship described in Vestergaard et al. 2006 (VP06). [5] Though time constraints precluded independent measurements for each galaxy in the sample, a small validation subset using SDSS DR7 spectral data and the VP06 scaling relation demonstrated extremely strong agreement with the mass estimates from the DR7 quasar catalogue.

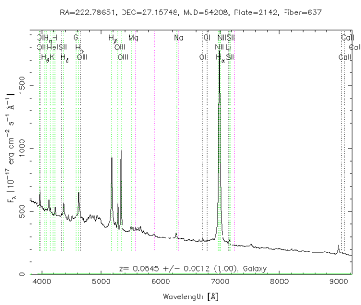

Figure 3: SDSS DR7 spectral data for mass estimates from galaxy at z = 0.0645

Results: Following thorough evaluation and analysis, 21 galaxies from the 75 galaxy sample possessed spiral structure measurable by the 2DFFT routine. Among those 21, 7 exhibited inconsistencies in spiral mode and stable radii which were sufficient to disqualify them from the study. Pitch angle measurements with uncertainties were acquired for the remaining 14 quasars, ranging from z = 0.06 through z = 0.4, which were then plotted against their respective supermassive black hole masses. Pitch angles for these galaxies were between 5 and 40 degrees, with percent errors generally around 10-15%. Masses fo the super massive black-holes were exclusively o the order o 10^7-10^8 sola masses. A least square fit was applied to t data, resulti in the equ tion: $\log_{10}(M_{BH})$ = $(8.36 \pm 0.33) - (0.026 \pm 0.009)P$, where P is the pitch angle in degrees, with a correlation coefficient of R^2 = 0.458 , indicating a moderate correlation. When compared to the established correlation for local, quiescent galaxies:

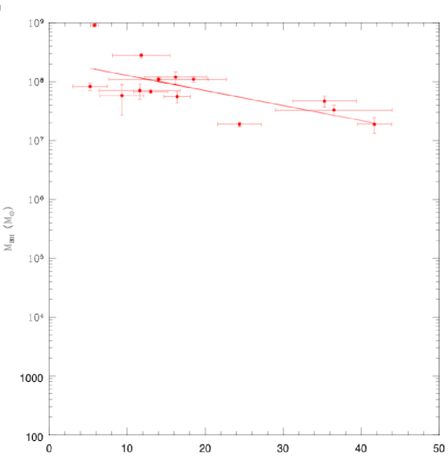

Figure 4: Pitch Angle Versus Black Hole Mass for Active, Intermediate Redshift Galaxies; The Solid Line is the Linear Fit of the Correlation

$\log_{10}(M_{BH}) = (8.44 \pm 0.10) - (0.076 \pm 0.005)P$ it is apparent that the line is shifted downward by 0.08 and the magnitude of the slope is decreased by 66%. This indicates that for active galaxies at intermediate redshift, black hole masses within tightly wound spirals are consistent with those for local, quiescent galaxies, but the mass falls off less quickly as the spiral becomes more open.

Conclusions: The data indicates that a moderate correlation between galactic central black hole mass and spiral arm pitch angle does exist for active spiral galaxies at intermediate redshift. However, the correlation differs from that established for local, quiescent galaxies, and is much less tight. The results herein indicate spiral arm pitch angle is less effective as an indicator for black hole masses in distant, active galaxies than in local, quiescent galaxies.

Unfortunately, the images obtained from the SDSS DR7 lacked sufficient resolution for high confidence pitch angle measurements. The 2DFFT code, which was validated and optimized with high resolution images of local galaxies, struggled with the more distant, lower resolution images in this study. The stable range of the galactic disk was often less than 10 pixels, providing very little information for the code to analyze. As such, the results herein are far from conclusive. Given higher quality images and less restrictive time constraints, more satisfying conclusions could be drawn. Future investigations utilizing higher quality image data are recommended to further evaluate the correlation.

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References: [1] M. Seigar, D. Kennefick, J. Kennefick, and C. Lacy. ApJ, 678:L93–L96, 2008.; [2] The Sloan Digital Sky Survey. (2011, May 11). Retrieved June 23, 2012, from Alfred P. Sloan Foundation website: http://www.sdss.org; [3] B. Davis, J. Berrier, D. Kennefick, J. Kennefick, C. Lacy, D. Shields, M. Seigar, and I. Puerari. ApJ Supplement Series, 199:33, 2012; [4]Shen, Y., et al. (2011, June 2). ApJ, 194(45). doi:10.1088/0067- 0049/194/2/45; [5] M. Vestergaard, and B. M. Peterson. ApJ, 641, 689, 2006