# Testing the Correlation between Spiral Arm Pitch Angle and Central Black Hole Mass

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## Abstract

In order to address the "cosmic downsizing problem," or the underpopulation of highly massive quasars in the current epoch, the Arkansas Galaxy Evolution Survey (AGES) is exploring a correlation, the M-P relation, between the pitch angle of a galaxy's spiral arms and the mass of its central supermassive black hole (SMBH). The goal is to generate a census of SMBH masses using only images, without relying on spectra. This study presents preliminary results testing the M-P relation by comparing the masses of a sample of active spiral galaxies as calculated by the pitch angle method with those calculated by the mass scaling relationship. Additionally, we present the null correlation between the pitch angle of spiral galaxies and redshift. The data set includes 225 galaxies from the GOODS North and South fields with redshifts out to z ~ 1.2. There does not appear to be any dependence of pitch angle on redshift. Consequently, if the relationship between pitch angle and SMBH mass has not evolved since z ~ 1.2, then the mean mass of SMBH has also remained constant. If, on the other hand, the relationship has evolved, then the mean mass has evolved inversely with the relationship. This conclusion is subject to further studies on possible selection effects.

## Spiral Arm Pitch Angle

The goal of the Arkansas Galactic Evolution Survey (AGES) is to contribute to the mass function of supermassive black holes, or the number of black holes that exist as function of mass.

Specifically, we have found a correlation between a black hole's mass and the pitch angle (The M-P relation) of the host galaxy's spiral arms (Seigar *et al*, 2008). The pitch angle is the spiral's deviation from a circle. A pitch angle of zero represents spirals that are wound completely into a circle, while a pitch angle of 90º represents radial spokes.

In general, more tightly wound spirals correlate to more massive black holes, as illustrated by Figure 1.

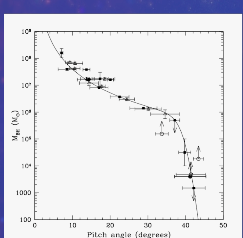
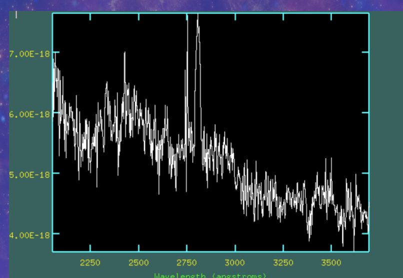



Figure 1: The M-P relation. Using the direct determinations of the central black hole mass of 27 nearby spiral galaxies, we have found a correlation between the central mass and the pitch angle of the spiral arms, with tighter spiral arms corresponding to higher black hole mass.

## Mass-Scaling Relationship

Testing the M-P relation at greater distances requires alternative techniques to determine the mass of the central black hole. One method we are exploiting is an empirical mass scaling relationship based on reverberation mapping of galaxies with an actively accreting central black hole. For this study, we have selected the Chandra Deep Field South to locate AGN with spiral structure. The mass of the central black hole is determined by using the emission line width as a measure for the broad-line region velocity and the continuum luminosity as a measure for the size of the broad-line region (McLure and Jarvis, 2002) Assuming a Keplerian orbit, we are able to estimate the black hole mass from single epoch spectra. The analysis is ongoing. Fig. 2 shows such a spectrum.




$$M_{\mathrm{M}} = 3.37 \left( \frac{L_{3000}}{10^{37}\ \mathrm{W}} \right)^{0.47} \left( \frac{\mathrm{FWHM_{MgII}}}{\mathrm{km\ s^{-1}}} \right)^{2} M_{\odot}$$

Fig.2: The spectrum shown here is from an active spiral galaxy at $z \approx 1$ with a spiral arm pitch angle of 18.1° ± 0.7°, which corresponds to a black hole mass of (1.2 ± 0.24) x$10^7$ solar masses according to the M-P relation. This spectrum has been corrected for Doppler broadening and has not had narrow-line component or host galaxy starlight subtracted. The MgII emission line (2798 Angstroms) has a full-width at half-maximum of 22 Angstroms and the continuum luminosity at 3000 Angstroms is 8.2x$10^{43}$ erg/s. With this single epoch spectrum, preliminary results from an empirical mass scaling relationship gives a central black hole mass of 1.7x$10^7$ solar masses. Although host starlight and narrow-lines have not been subtracted, the narrow-line component causes an underestimation of the BH mass and the host galaxy luminosity causes an overestimation of the BH mass, effectively canceling each other out.

## Evolution of Pitch Angle

The pitch angles of galaxies were measured back to a redshift of about 2. The data set includes 225 galaxies from the GOODS North and South fields. The sample was 90% complete at a redshift of 1.2.

The completeness of the sample was estimated through a process called artificial dimming. Using each galaxy's observed magnitude and redshift, one can determine the maximum distance at which the galaxy would be visible in a given image. Figure 3 shows the artificially dimmed GOODS sample.

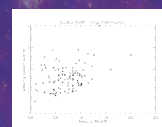


Figure 3: Artificial dimming of 115 galaxies from the GOODS North field. The horizontal axis is the measured redshift, and the vertical axis is the farthest redshift at which the galaxy would be visible in our sample. This analysis assumes that the galaxies are point sources.

The model used in Figure 3 is simplistic because it assumes that the galaxies are point sources. The unphysically large scale of the vertical axis illustrates the limitations of the point source model. The next step will be to consider the galaxies as extended sources, and finally as spiral sources.

While the point source model renders the upper half of the graph untrustworthy, the lower half of the graph passes numerical tests. It suggests that 90% of our galaxies would be visible at a redshift of 1.2, which corresponds to a distance of about 7 billion light years. Therefore the sample is, to a point source approximation, 90% complete at a redshift of 1.2.

Figure 4 shows pitch angle vs. redshift. There does not appear to be any dependence of pitch angle on redshift. Consequently, if the relationship between pitch angle and SMBH mass has not evolved since z ~ 1.2, then the mean mass of SMBH has also remained constant. If, on the other hand, the relationship has evolved, then the mean mass has evolved inversely with the relationship. This conclusion is subject to further studies on possible selection effects.

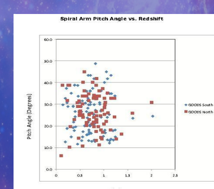



Figure 4: Pitch Angle versus redshift for 225 galaxies in the GOODS North and South fields. A linear regression shows that the mean pitch angle has remained roughly constant since z ~ 1.2.

## References

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## Acknowledgements:

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