The variables $P$ pitch angle (displayed below) which is parameterized by an exponential function of the value of the pitch angle $P$ of the spiral galaxy:

$$r = e^{\theta \cdot \tan(P)}$$

In 2008, the Arkansas Galaxy Evolution Survey (AGES) discovered a relationship between spiral arm pitch angle, $P$ and SMBH mass [1]:

This graph relates the mass of a SMBH (in solar masses) to the pitch angle of the host spiral galaxy. From the plot, one can see that the SMBH mass increases as the pitch angle decreases. Therefore, the tighter the spiral galaxy, the greater the SMBH mass.

By using this data and following the Nuker Law[2], a formula was derived to relate the mass of a SMBH to the spiral arm pitch angle of the host galaxy:

$$M_{BH} = 2^{(\beta - \gamma)/\alpha} M_{BH_0} \left(\frac{P}{P_b}\right)^{\alpha (\beta - \gamma)/\alpha} \left[1 + \left(\frac{P}{P_b}\right)^{\alpha \gamma}\right]$$

The variables $\alpha, \beta, \gamma$ are just constants to make this function have a Nuker profile. Furthermore, $M_{BH_0}$ and $P_b$ are just reference values, making the value of the pitch angle $P$ the only variable in this equation. Thus by only knowing the pitch angle of a spiral galaxy, the mass the SMBH at the center of the galaxy can be determined. Thus if the pitch angle of a spiral galaxy is known, then the mass of the central SMBH can be determined.

Introduction:
The degree to which spiral galaxy arms deviate from being a perfect circle is called the pitch angle, $P$ of the spiral galaxy. Thus a circle has a pitch angle of 0 degrees, while a spoke has a pitch angle of 90 degrees.

The core geometry of all spiral galaxies has the shape of a logarithmic spiral (displayed below) which is parameterized by an exponential function of the pitch angle $P$ of the spiral galaxy:

$$r = e^{\theta \cdot \tan(P)}$$

Experiment:
Using the Hubble Space Telescope (HST), many spiral galaxies and clusters of spiral galaxies with red shifts ranging from $z = 0.1$ to $z = 1.3$ were collected for observation from various Hubble fields. Samples include:

However, upon collection from the HST, most galaxies are not face-on with the telescope. For images to be properly analyzed, the galaxy must be straight-on, and further analyses require the image of the galaxy to be a perfect circle. Therefore, the Image Reduction and Analysis Facility (IRAF) is used to re-project the image of the galaxy. This process is used to determine the ellipticity, which is utilized to project the image to a circle.

To correct the image, IRAF is first used to take the original image and generate a contour plot of isophotes, or regions of constant luminosity, of the galaxy. This plot is used to determine the ellipticity, which is utilized to project the image to a circle.

Now that the image is circular and face-on, a Fast Fourier Transform (FFT) of the image of the galaxy is performed. This results in the image of the galaxy showing only the present periodicity in the galaxy. Hence, all that remains in the image is the spiral structure of the galaxy. Any non-periodic features such as interstellar media, radiation jets, or accretion disks are not present in the FFT, allowing for easy detection of the spiral arm geometry.

With the FFT result, IRAF is used to easily measure the pitch angle of the galaxy. Therefore, since pitch angle is known, the mass of the central SMBH is easily determined from the Nuker model equation. This process is repeated for every spiral galaxy investigated in this study.

Results:
A total of 61 spiral galaxies were examined, and pitch angles were determined for each in order to measure the mass of their central SMBH by using the Nuker Model. The results are displayed on the following plot:

To further justify this method of determining SMBH mass, pitch angles of spiral galaxies with known SMBH masses[3] were measured and compared to the Nuker Model.

Conclusions:
This study shows a very simple and efficient method to measuring the masses of SMBH at the center of spiral galaxies. The plot above showing known SMBH mass and pitch angle is a clear indicator that this method is also a precise way to measure SMBH mass. Previous methods for measuring SMBH required long term measurements of spectral lines, velocity distributions, reverberation mappings, and luminosities of the host galaxies. On the contrary, the pitch angle method requires only an image of a galaxy in order to measure the mass of a SMBH.

Knowing the mass of a SMBH is critical in the study of dark matter, the mass function of the universe, and galactic dynamics. Further studies are looking at how pitch angle is perturbed by having a galaxy located in a galaxy cluster. This study displays the easiest possible way to measure black hole mass.

Contact: Brad Dinardo; Juniata College
Email: dinarba07@juniata.edu

References & Acknowledgements:

Brad Dinardo¹,², Ben Davis¹, Daniel Kennefick¹, Julia Kennefick¹
¹University of Arkansas; Arkansas Center for Space & Planetary Sciences, Fayetteville, AR
²Juniata College; Department of Physics, Huntingdon, PA