Measuring Mass of Super Massive Black Holes by Examining Spiral Galaxy Pitch Angle

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1 Introduction

It is theorized and widely accepted that at the center of nearly all spiral galaxies lies a Super Massive Black Hole (SMBH). The gravitational potential provided by the SMBH plays a crucial role in the structure and geometry of its host spiral galaxy—especially with how tightly wound the spiral arms are. The larger the gravitational potential (i.e. the more massive SMBH), the greater the tendency for the spiral arms to be more attracted to the center, resulting in a tighter spiral galaxy. Thus a correlation exists between how tightly wound a spiral galaxy is and the mass of the SMBH at the center of the galaxy. Simply by using a telescope to obtain images of spiral galaxies, the mass of host SMBH can readily be measured by calculating spiral pitch angle. This provides a very simplistic and relatively quick method to determine SMBH mass.

Spiral Galaxy Pitch Angle

The core geometry of all spiral galaxies has the shape of a logarithmic spiral. The degree to which the spiral arms deviate from being a perfect circle is called the pitch angle, ϕ of the spiral galaxy. For any given logarithmic spiral, the pitch angle is a function in cylindrical coordinates of distace from the origin r and angular position θ:

$$\cot\phi = r\frac{d\theta}{dr} \tag{1}$$

From equation 1, it can be shown that the parametric equation describing a spiral galaxy is

$$r = e^{\phi\tan\theta} \tag{2}$$

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

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

$$M_{BH} = 2^{\frac{\beta-\gamma}{\alpha}} M_{BH_b}\left(\frac{\phi_b}{\phi}\right)^{\gamma}\left[1+\left(\frac{\phi_b}{\phi}\right)\right]^{\frac{\gamma-\beta}{\alpha}} \tag{3}$$

where α, β, γ are constants to allow this function to take on a Nuker profile[2]. Furthermore, M_{BH_b} and ϕ_b are reference points of known black hole mass and known pitch angle of a given galaxy. Thus by only knowing the pitch angle of a spiral galaxy, the mass the SMBH at the center of the galaxy can be determined.

2 Experiment

Using the Hubble Space Telescope (HST), many spiral galaxies and clusters of spiral galaxies with redshifts ranging from $z = 0.1$ to $z = 1.3$ were collected for observation. 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 deproject the image such that the galaxy is face-on and is perfectly circular.

To correct the image, IRAF is first used to take the original image and generate a contour plot of isophotes 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 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 only 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, equation 3 is used to determine the mass of the central SMBH. This process is repeated for every spiral galaxy investigated in this study.

3 Results

A total of 61 spiral galaxies from Hubble fields were examined, and pitch angles were determined for each in order to measure the mass of their central SMBH by using equation 3.

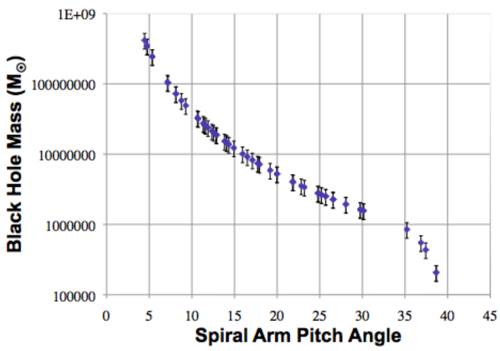

Figure 1: *SMBH masses determined by measuring spiral arm pitch angle and using the Nuker model. Error bars show 25% error.*

To futher justify this method of determining SMBH mass, pitch angles of spiral galaxies with known SMBH masses were measured and compared to the Nuker Model[3]. The results are displayed on the following plot.

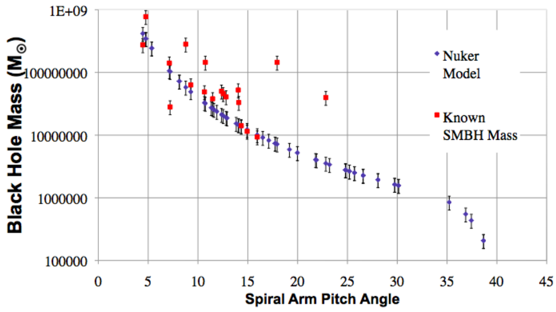

Figure 2: *This plot contains SMBH masses determined by measuring spiral galaxy pitch angle. The blue series is mass calculated with the Nuker Law and the red series consists of known SMBH mass with their respectively measured pitch angles.*

4 Conclusions

This study shows a very simple and efficient method to measuring the masses of SMBH at the center of spiral galaxies. The comparison shown in Fig. 2 between known SMBH mass and experimental 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, and luminosities of the host galaxies. This 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. This study displays the easiest possible way to measure black hole mass.

5 References

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