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A comparison of black hole mass scaling relations and galactic morphologies of spiral galaxies

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We investigated the relationships between black hole mass scaling relations and the galactic morphologies of spiral galaxies using density wave theory. Drawing on spiral arm pitch angle measurements, the theory predicts a correlation between these angles and the wavelengths observed in galaxy images. The study involved 20 grand-design spiral galaxies belonging to the NGC catalogue with clearly visible spiral arms, including both inner and outer arms. We deprojected the original images to face-on orientation using the IRAF package and parametric data from the NED and HyperLeda databases. Pitch angles were measured visually using the Python-OL script, and a pitch angle range was evaluated using six wavebands: 3.6 μm , 8.0 μm , B-band, H α , HI, and CO. Pitch angles were then individually determined for each spiral arm using a MATLAB-based script SPIRALITY. When comparing with existing literature values this study revealed discrepancies in spiral arm pitch angle measurements across several galaxies. These discrepancies were mainly due to variations in the inclination angles of these galaxies. As the theory predicted, we noticed the wavelength dependence of the pitch angle. The pitch angle measurements in wavebands 3.6 μm and 8.0 μm , B and 8.0 μm , and H α and 8.0 μm showed a 1:1 correlation. Central supermassive black hole (SMBH) masses and dark matter halo (DMH) masses were determined using standard scaling equations for 3.6 μm waveband pitch angles. We used average spiral arm pitch angles to calculate masses for both the inner and outer arms separately. We discovered that the average pitch angle of inner arms determines the black hole mass of a galaxy with both inner and outer arms, as per existing literature. The study found an SMBH mass-pitch angle relation, $\log\left(\frac{M_{BH}}{M_{\odot}}\right) = (6.69 \pm 0.64) - (0.001 \pm 0.030)(|\phi|)$ and proposed four other SMBH mass-pitch angle relations for Inner, Inner-Outer, SAB, and Pseudobulges. The SMBH mass calculations presented in this work are in good agreement with available direct measurements. This spiral arm pitch angle based SBHM mass estimation model is suitable for determining the black hole masses of galaxies with an inclination angle between 7° - 22°. The DMH mass-pitch angle relation was found to be, $\log\left(\frac{M_{DM}}{M_{\odot}}\right) = (-0.02 \pm 0.02)(|\phi|) + (12.17 \pm 0.33)$ for the sample. We proposed an SMBH mass - DMH mass relation, $\log\left(\frac{M_{BH}}{M_{\odot}}\right) = (4.07 \pm 0.03)\log\left(\frac{M_{DM}}{M_{\odot}}\right) - (41.69 \pm 0.40)$ for the sample, and another two relations for galaxies with inner arms and those with both inner and outer arms. We examined the variations of SMBH and DMH masses in host galaxies, identifying three morphological subcategories: SA, SAB, and SB morphologies; (s) and (rs) morphologies; and ab, b, bc, c, and cd morphologies. A normalised form of black hole mass and dark matter halo mass, K_D , was defined and plotted against these morphologies. Results showed that the K_D in barred morphology decreases from unbarred to barred, the spiral feature decreases from complete spiral (s) to mixed spiral (rs), and the Hubble subtype decreases from 'b' to 'c'. The highest K_D of morphological subtypes SA, (s), and 'b' are identified for each morphological subcategory separately.

Keywords: Black hole mass, Dark matter halo mass, Galactic morphology, Pitch angle, Spiral galaxies