Uncovring the Census of Massive Black Hole in Nearby Sub-Milky Way Mass (Sub-MWm) Galaxies with ALMA

Dieu Nguyen[1], Satoru Iguchi[1], Michele Cappellari[2], Jenny Greene[3], Mark den Brok[4]

[1] *NAOJ (Japan)*, [2] *University of Oxford (UK)*, [3] *Princeton University (USA)*, [4] *AIP (Germany)*

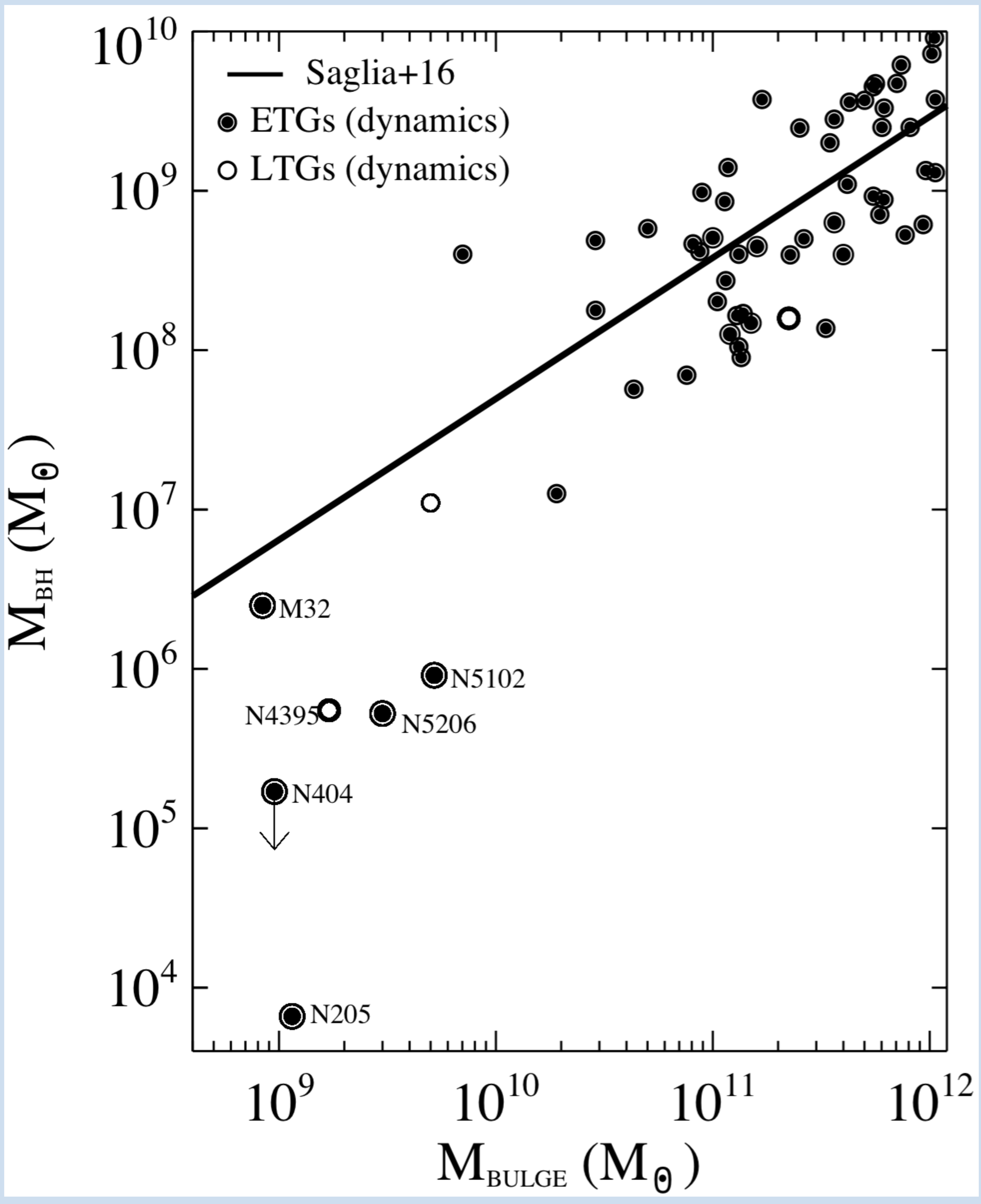
The Importance of Massive Black Holes (BHs) in Sub-MWm Galaxies

(1) Observations confirm the existence of BHs at the centers of massive galaxies and their masses correlate tightly with the macroscopic properties of the hosts (e.g., dispersion). However, our knowledge of this picture in Sub-MWm galaxies is currently incomplete due to lacking measurements.

(2) Finding and weighting BHs in Sub-MWm galaxies are challenging. However, their mass are important to constrain: (i) the "occupation fraction" parameter, which is necessary to investigate the unknown formation mechanisms of the BH seeds in the early universe (light seeds vs. massive seeds), (ii) the BH number density, the key measurement to study the number of BHs we expect to find in stripping galaxy nuclei or tidal disruption rate, and (iii) the slopes & scatters of the BH mass and galaxy's properties scaling relations at the low-mass end, which imply BHs and their host galaxies form and co-evolve throughout the cosmic history.

Motivations

(1) Current BH mass ($M_{\rm BH}$) measurements revealed remarkable $M_{\rm BH}$–galaxy scaling relations, although these measurements are strongly biased to massive and early-type host galaxies (ETGs). Only a handful of $M_{\rm BH}$ measurements in sub-MWm galaxies using adaptive optics (AO) observations have been conducted, mostly restricted to a subsample of 5 ETGs, raising the urgently necessary of having more $M_{\rm BH}$ measurements in this important galaxy mass regimes.



(2) Scaling relations of sub-MWm galaxies ($M_{\rm BH} \lesssim 10^6 M_\odot$) show surprises: (i) A factor of two difference in normalization is seen when fitting $M_{\rm BH}$–σ for ETGs and LTGs separately. (ii) There is large scatter below the global scaling relations. (iii) Detection some $<10^6 M_\odot$ BHs in nearby ETGs hints these objects fall below the $M_{\rm BH}$–$M_{\rm bulge}$ relation extrapolated from higher mass galaxies in a wide range of 1–3 orders of magnitude of $M_{\rm BH}$ (see Fig.).

Aims

We aim to solve above problems by targeting nearby sub-MWm galaxies only, but across the Hubble sequence from late-type galaxies (LTGs) to ETGs. Our goal is to obtain a census of local BHs in sub-MWm galaxies, which is currently missing. We believe a homogenous technical and modeling approach using the world-leading ALMA interferometric array can achieve the breakthrough in (1) uncovering the demographics of BHs in sub-MWm galaxies and (2) understanding co-evolution with their host galaxies.

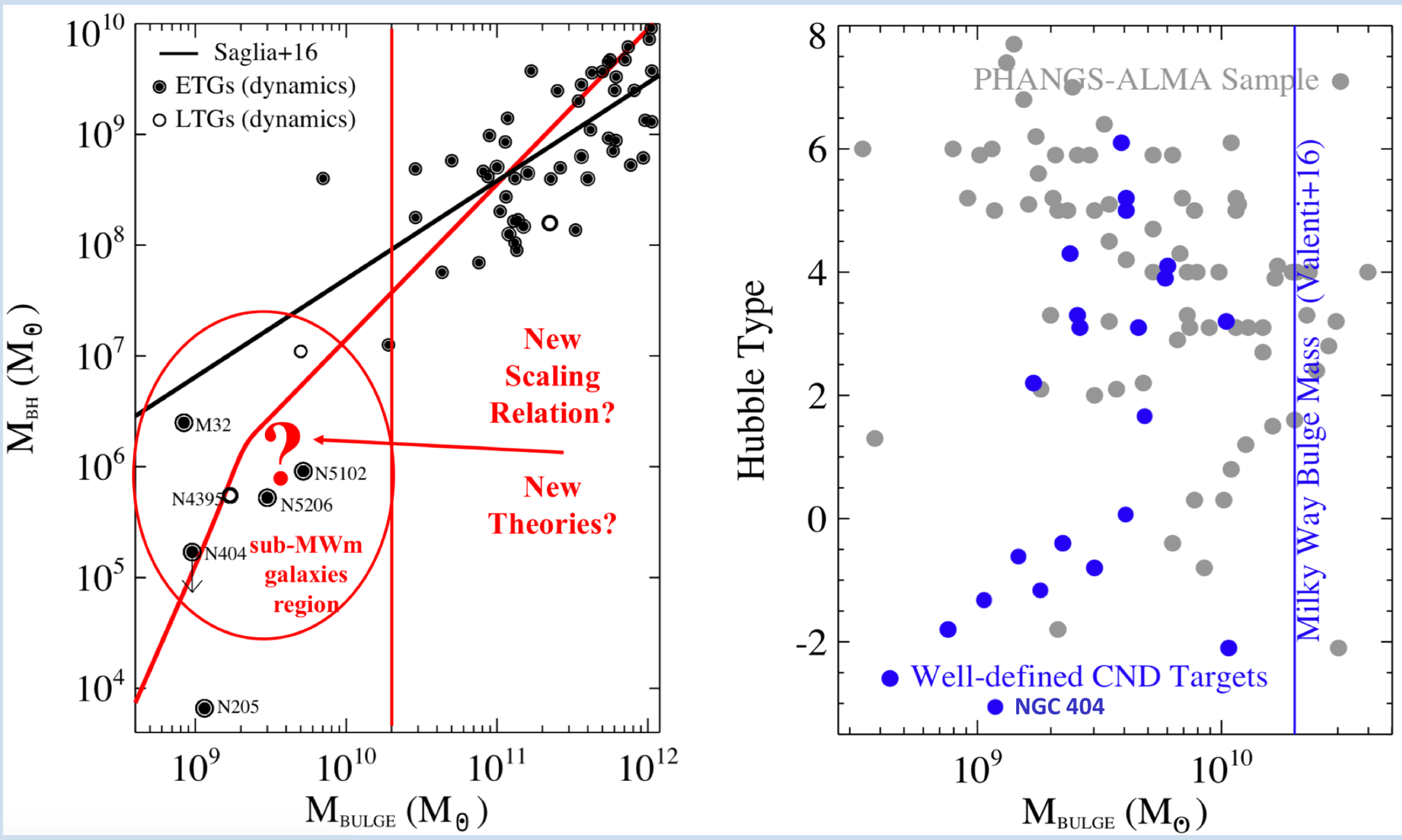
The Measuring BH Masses in sub-MWm Galaxies Project

(1) We have been gathering a large sample of sub-MWm gas-rich galaxies, measuring their central dark masses, which are likely BHs, using molecular gas tracers (e.g., ^{12}CO(2 − 1)) observed with ALMA, then characterizing the full spectrum of BH populations across the Hubble sequence because of the high angular resolution and superb sensitivity.

(2) This project improves on many problems affecting $M_{\rm BH}$ measuremnts via existing optical/infrared instruments including (1) high angular resolution capable of resolving the sphere of influence (SOI) and (2) ability to obtain dynamical measurements in dusty/obscured nuclei, which are inaccessible at optical wavelengths. The physical idea behind the cold gas-dynamical method utilizing the observations of ALMA is that the $M_{\rm BH}$ is derived by detecting and resolving the Keplerian turnover motion of the cold gas disk at the galactic center directly (within SOI). However, this method works well for gas-rich galaxies those host well-defined and rotating circumnuclear gas disks (CNDs) only.

Sample Selection

We select targets based on the presence of well-defined CNDs of gas and dust, which serve as morphological evidence for rotating dense gas about galaxy centers based on previous PHANGS–ALMA low-spatial-resolution surveys. 20 targets for $M_{\rm BH}$ measurements have already been observed/proposed by ALMA in Cycles 5 and 7 (right plot). Ideally, we hope to assemble a large sample of ∼30–40 suitable targets (left plot, $M_{\rm Bulge} < 2\times10^{10} M_\odot$, combining this with the current <10 $M_{\rm BH}$ constraints, we will have a sample that is as large as 50% comparison to the higher masses sample) to have a well statistical constraints on the local BH mass density and $M_{\rm BH}$–galaxy scaling relations. This sub-sample is the first step towards this effort.



Analysis Plan

(1) Requesting Data, Imaging, & Modeling: We plan to (1) add more promising candidates to our sample in future ALMA Cycles when the full PHANGS–ALMA survey data is available; (2) imaging the data, which were full observed, calibrated and delivered to us; and (3) constructing dynamical modeling (e.g., KinMS, Tilted-ring) to optimize data vs. model and BH masses.

(2) Interpretation: We will use $M_{\rm BH}$ measured by a homogenous technical and modeling approach to determine the demographics of BHs in sub-MWm galaxies and co-evolution scenario of BHs and their host galaxies. Also, a robust estimate of $M_{\rm BH}$ function can provide critical information about BH growth histories and place constraints on the mean radiative efficiency of BH accretion.

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