1. Low Surface Brightness Galaxies

LSBGs are galaxies with surface brightnesses below the night sky and thus are underrepresented in catalogs. However, LSBGs comprise about half of local galaxies and perhaps about half of local massive black holes. The formation of LSBGs and the role of MBH feedback are open questions. LSBGs span a range in size and morphology, and tend to have higher gas mass and lower stellar mass than normal galaxies of the same dynamical mass, which may indicate “high spin” dark matter halos.

2. Black Hole Occupation Fraction

The large LSBG fraction makes them relevant to discover how galaxies got MBHs. Two possibilities are direct gas collapse into a $10^{10}$ $M_\odot$ BH (heavy seeds) or else $<10^5$ $M_\odot$ compact remnants of Pop III stars (light seeds). In the former case, many small galaxies may lack MBHs, so the correct channel can be identified by measuring the occupation fraction ($f_{\text{occ}}$).

Determining $f_{\text{occ}}$ requires measuring the absence of MBHs, which are generally only detectable through their activity. Hence, we must simultaneously constrain the active fraction and $f_{\text{occ}}$ at each mass (Miller et al. 2012, 2015), which requires large, unbiased samples. LSBGs can double the number of targets in a given volume.

High resolution X-ray images are the best way to detect faint MBH activity but one must account statistically for X-ray binary contamination based on the stellar mass and star formation rate (Ford et al. 2017; Lee et al. 2019).

3. Chandra Survey of LSBGs

We performed a Chandra Successor Mission survey of 34 LSBGs (d<75 Mpc) to determine whether their nuclear activity is consistent with normal galaxies of the same mass and whether they are useful for determining $f_{\text{occ}}$ with a large, high-resolution X-ray camera (Lynx HXDI or AXIS). The sample was selected to match the mass distribution for the AMUSE-Field Chandra survey of normal galaxies (Miller et al. 2012) when considering total baryonic mass ($M_{\text{BH}}+M_\ast$).

8/34 of the galaxies had archival data (Das et al. 2009). The remainder were observed to sensitivities similar to AMUSE-Field in order to test consistency.

5/34 LSBGs had a nuclear X-ray detection. The SFR and stellar mass enclosed by the Chandra aperture indicates a <8% chance of 1 or more detectable, nuclear X-ray binaries.

4. LSBGs and Black Hole Growth

The LSBG distribution of $L_X$ with $M_\ast$ (red points) is consistent with the best-fit relation in normal galaxies (dashed line) from AMUSE-Field (black points). However, too many LSBGs are undetected if the relation follows total mass instead (blue points). This indicates that MBHs co-evolve with the stellar component.

In general, we expect larger black holes in more massive systems, and thus (for similar Eddington ratios) higher $L_X$ with higher $M_\ast$. This allows us to determine how many non-detections are allowed at some $f_{\text{occ}}$ for a given sensitivity. Miller et al. (2015) measured the $L_X-M_\ast$ relation for normal field galaxies, where the gas-mass fractions are small. With 34 LSBGs we cannot independently measure this for our sample, but we can test whether LSBGs are consistent. We find 4-5 detections are expected if MBHs scale with stellar mass but not total baryonic mass. That is, MBHs appear related to stellar mass but not dynamical mass.

Here we account for scatter in the $L_X-M_\ast$ relation. 4-5 detected MBHs (in blue) corresponds with the expectation if LSBGs follow the AMUSE-Field relation, but occur <5% of the time if $L_X$ correlates with total mass instead of stars.

5. Prospects for Lynx

LSBGs are common, should have lower nuclear X-ray binary contamination than normal galaxies, and can provide a larger sample for measuring $f_{\text{occ}}$. This will be key to determining the endpoint of black hole growth, anchoring LISA gravitational wave measurements, and testing seed formation theories (along with Lynx deep surveys).

When combining future $f_{\text{occ}}$ constraints with the galaxy luminosity function from the Galaxy and Mass Assembly survey, one can constrain the BH mass function below $10^5 M_\odot$ to <1% (Gallo & Sesana 2019). Current constraints are restricted to massive galaxies where $f_{\text{occ}}$ ~1 is always expected.

High resolution, high sensitivity imaging is needed to isolate faint nuclear emission. In its surveys and observations of clusters or groups, Lynx should serendipitously observe thousands of LSBGs from which we can expect hundreds of detections and constrain $f_{\text{occ}}$ to a few percent (for details see Astro2020 WP by Gallo et al. 2019).

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