Massive Black Holes in Low Surface Brightness Galaxies

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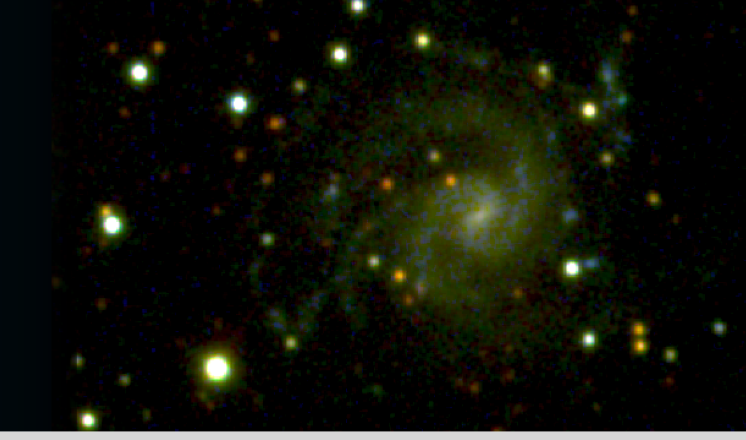


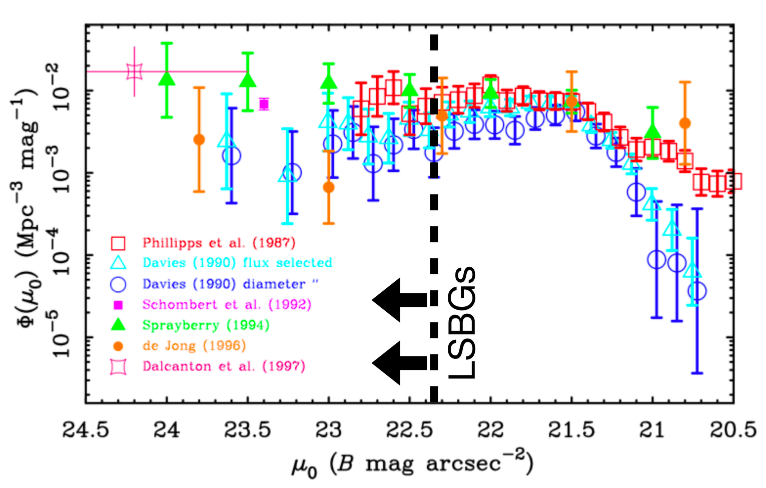
What did we do? An unbiased Chandra survey of nuclear activity in 34 low surface brightness galaxies (LSBGs) within ~75 Mpc.

Why did we do it? To gain insight into massive black hole (MBH) growth and probe the ability of LSBGs to constrain the local MBH occupation fraction.

What did we learn? MBHs in LSBGs correlate with $M_\star$, not $M_\star+M_{gas}$.
LSBGs as Lynx serendipitous sources will constrain MBH occupation.

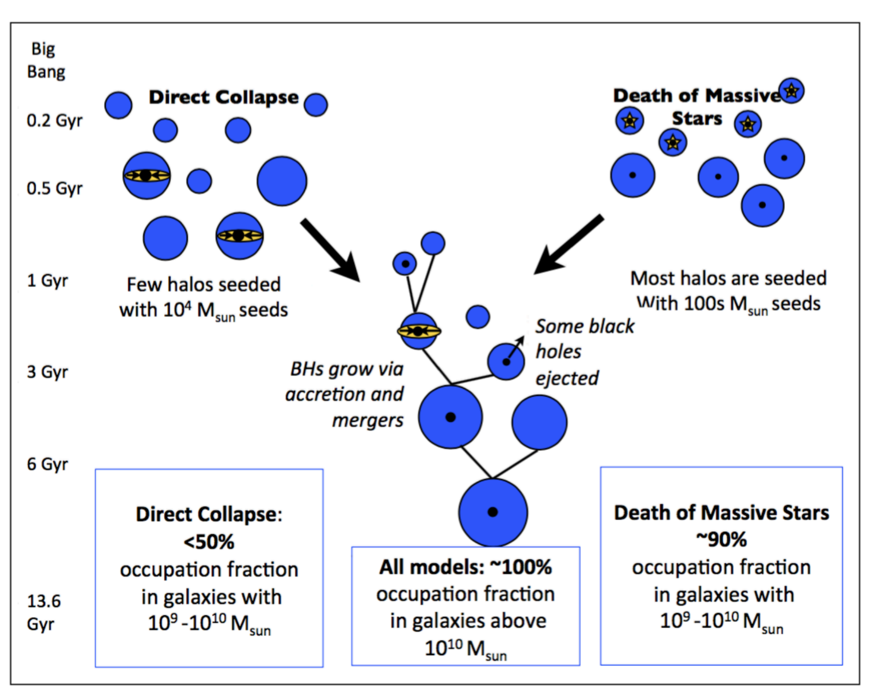
1. Low Surface Brightness Galaxies

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.



The volume density of LSBGs (McGaugh 1999) implies that half of local galaxies are LSBGs.

2. Black Hole Occupation Fraction

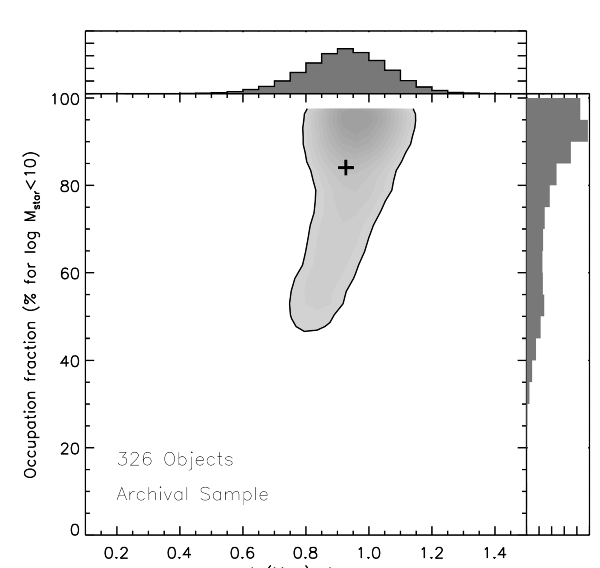


The occupation fraction can distinguish between rare, massive (direct collapse) seeds and common, smaller supernova remnant seeds (Volonteri 2012).

The large LSBG fraction makes them relevant to discover how galaxies got MBHs. Two possibilities are direct gas collapse into a 10^{4-6} $M_\odot$ BH (heavy seeds) or else ~10^2 $M_\odot$ 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_{occ}).

Determining f_{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_{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.

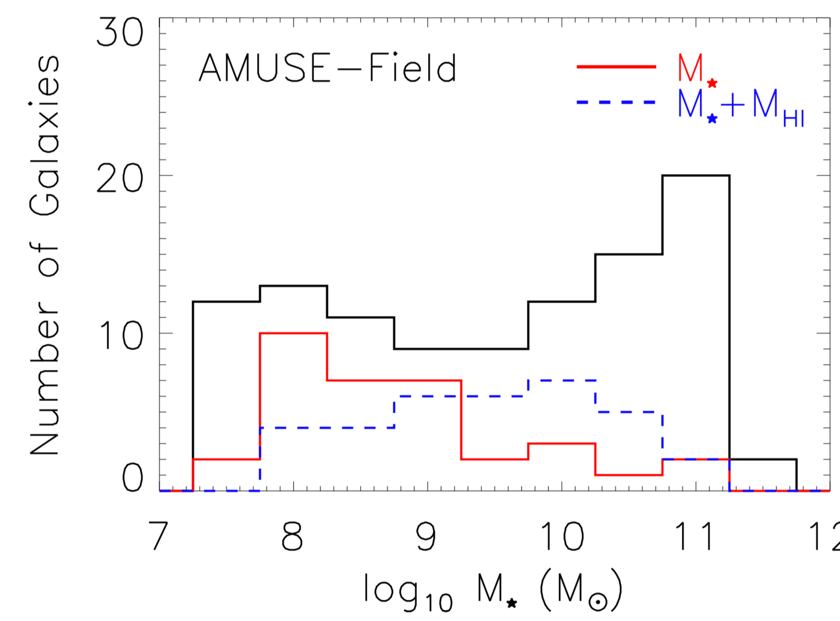
High resolution X-ray images are the best way to detect faint MBH activity but one must account statistically for X-ray binary contamination based on the stellar mass and star formation rate (Foord et al. 2017; Lee et al. 2019).



We currently cannot rule out 100% occupation with >95% confidence (Miller et al. 2015), but with ~3000 galaxies f_{occ} can be measured to a few percent accuracy (Gallo 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_{occ} with a large, high-resolution X-ray camera (*Lynx* HDXI 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 ($M_{HI}+M_\star$).

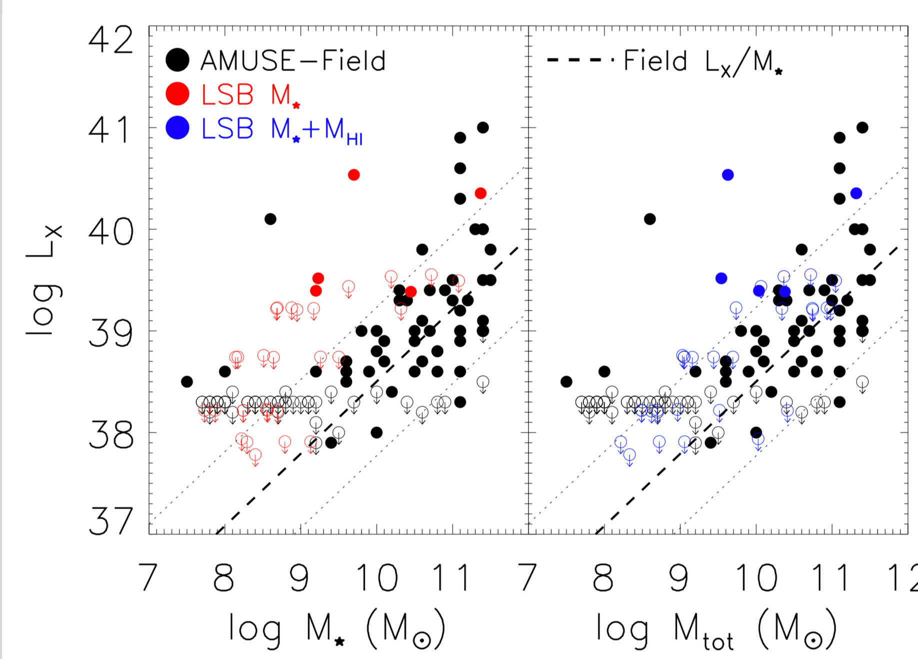


The LSBG baryonic (and inferred dynamical) mass distribution (blue line) is consistent with the AMUSE-Field sample (black), but the stellar mass (red) is not.

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.

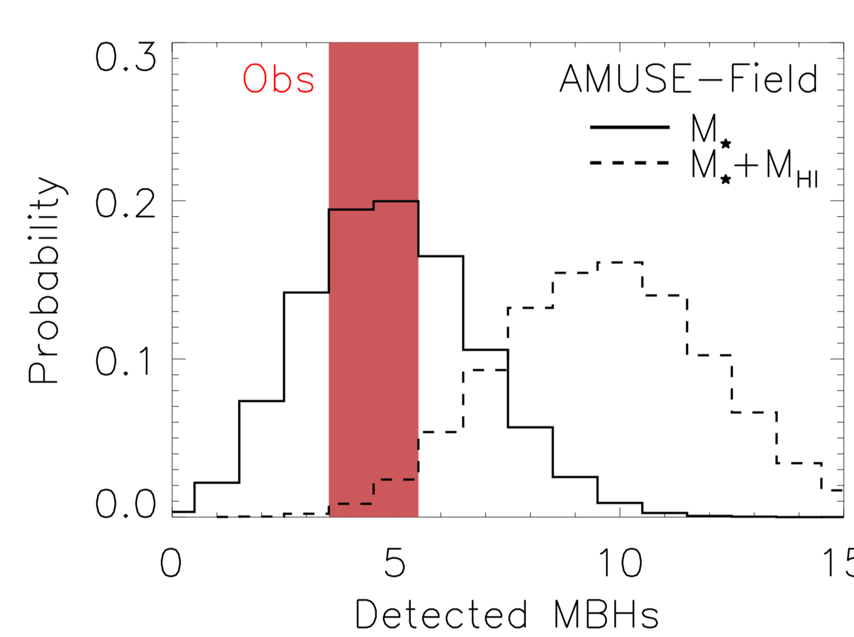
5/34 LSBGs had a nuclear X-ray detection. The SFR and stellar mass enclosed by the *Chandra* aperture indicates a <8% chance of 1 or more detectable, nuclear X-ray binaries.

4. LSBGs and Black Hole Growth



The LSBG distribution of L_X with $M_\star$ (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.

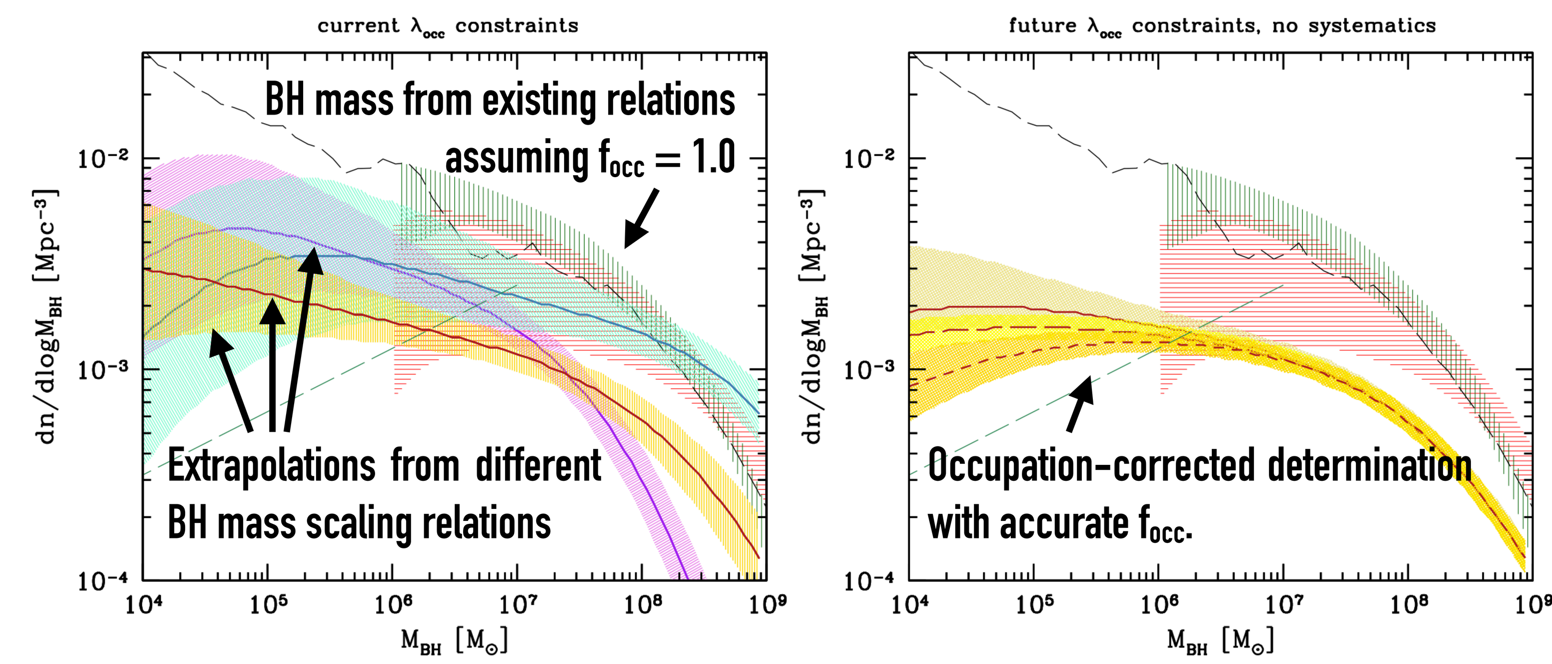
In general, we expect larger black holes in more massive systems, and thus (for similar Eddington ratios) higher L_X with higher M. This allows us to determine how many non-detections are allowed at some f_{occ} for a given sensitivity. Miller et al. (2015) measured the L_X-$M_\star$ relation for normal 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 that 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 $L_X/M_\star$ relation. 4-5 detected MBHs coincides 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.

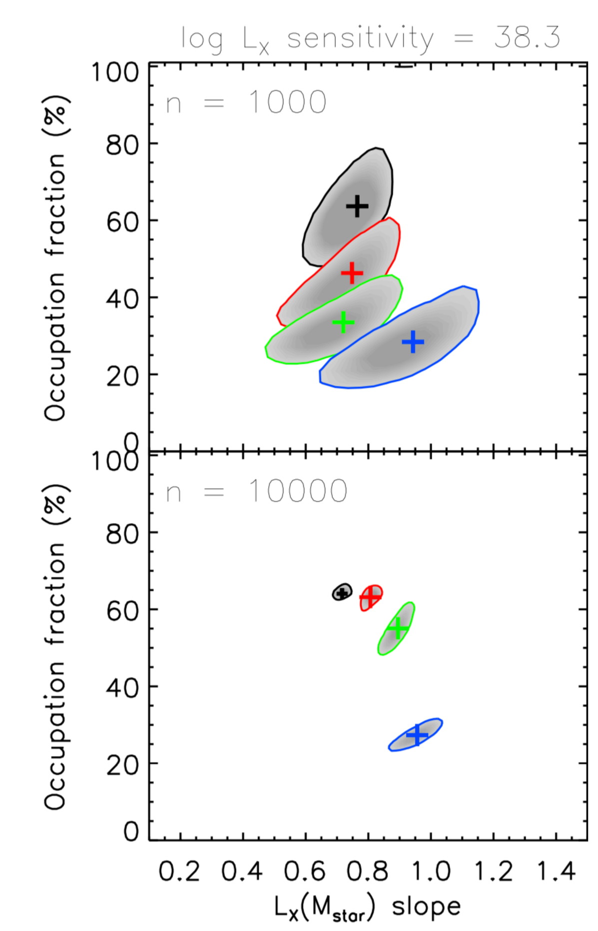
5. Prospects for Lynx

LSBGs are common, should have lower nuclear X-ray binary contamination than normal galaxies, and can provide a larger sample for measuring f_{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).

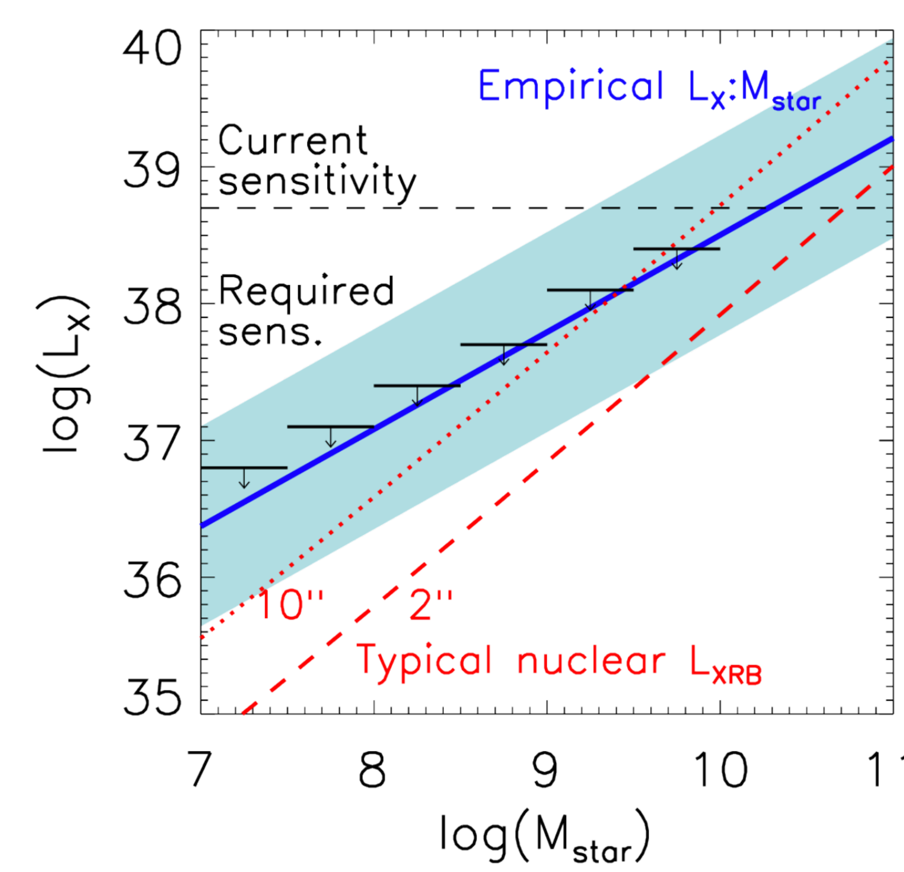


When combining future f_{occ} constraints with the galaxy luminosity function from the Galaxy and Mass Assembly survey, one can constrain the BH mass function below 10^6 $M_\odot$ to <1 dex (Gallo & Sesana 2019). Current constraints are restricted to massive galaxies where f_{occ}~1 is always expected.

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_{occ} to a few percent (for details see Astro2020 WP by Gallo et al. 2019).



f_{occ} constraints with 1,000 vs. 10,000 galaxies for four inputs. With mass distribution optimization (see example at right), the bottom plot is possible with 3,000 galaxies.



Current surveys do not constrain f_{occ} below 10^{10} $M_\odot$. Better sensitivity is needed, since we expect smaller MBHs and lower L_X. Since higher sensitivity will also pick up more X-ray binaries, high resolution imaging is needed to isolate faint nuclear emission.

References and Acknowledgments

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