Detecting Low-Mass Supermassive Black Holes

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Abstract. We demonstrate the feasibility of uncovering supermassive black holes in late-type, “quiescent” spiral galaxies by detecting signs of very low-level nuclear activity. We use a combination of x-ray selection and multi-wavelength follow-up. Here, we apply this technique to NGC 3184 and NGC 5457, both of type Scd, and show that strong arguments can be made that both host AGNs.

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INTRODUCTION

As discussed in Mathur et al. (these Proceedings) and in [1], the only way to detect low-mass supermassive black holes (SMBHs) may be by their accretion activity. We choose to use x-ray selection to identify candidate AGNs for the following reasons: First, x-ray emission is a hallmark of AGNs. Second, x-rays can penetrate obscuring material which may be hiding the line emitting regions. Third, there are fewer sources of x-rays in a galaxy than there are of optical and UV emission and so dilution of the AGN signature by host galaxy light is less of a problem, even if the AGN is moderately obscured. Fourth, even if, as expected in some theories [2, 3] AGNs that have luminosities or accretion rates below a cut-off value do not have broad-line regions, they should still be detectable in x-rays. The disadvantage is that x-ray observations by themselves cannot always distinguish between AGNs and other x-ray sources, such as x-ray binaries (XRBs) and ultraluminous x-ray sources (ULXs). Multi-wavelength data are needed to determine the type of source.

As examples, we present here two late-type spiral galaxies, NGC 3184 and NGC 5457 (M101). Their nuclear optical spectra show no signs of AGNs [4]. But using archival Chandra data and multi-wavelength data from the literature, we show that the sum total of evidence strongly suggests that the galaxies host AGNs.

NGC 3184

This galaxy is of type Scd, classified as having an HII nucleus by Ho et al. [4], and is at a distance of 8.7 Mpc [5]. The argument for the presence of an AGN is based on the following: (a) The nucleus is an x-ray source. Observations with Chandra totaling 60 ks detect a point-like source with 36 counts and a more extended component with 117 counts (Fig. 1). Assuming a power-law spectrum with slope $\Gamma \sim 2$ and correcting for
FIGURE 1. *Chandra* images of the nuclei of NGC 3184 (left) and NGC 5457 (right). Both panels are 10″ on a side and have north up and east to the left. **NGC 3184:** The nucleus consists of a point-like source and an extended component to the south of it. The bar on the lower left corresponds to a distance of ∼80 pc. **NGC 5457:** The nucleus is resolved into two sources, marked “N” and “S” in the figure. Source N is the active nucleus and source S is a star cluster. The bar on the lower left corresponds to a distance of ∼70 pc.

Galactic absorption only, the point source has luminosity $L(0.3–8\text{keV}) \sim 2 \times 10^{37}$ erg s$^{-1}$. Luminosities in this range are typically associated with XRBs rather than AGNs, but does not rule out an AGN, especially since intrinsic absorption is unknown. (b) *Infrared line ratios are not that of an H$\text{II}$ nucleus but instead suggest the presence of an AGN component.* A stronger argument that the source is an AGN derives from infrared data. This galaxy is part of the *Spitzer* Infrared Nearby Galaxies Survey [6]. Dale et al. [7] have used the equivalent width of the PAH feature at 6.2 μm and the fluxes in a mix of high- and low-ionization IR lines of S, Ne, and O to create diagnostic diagrams that distinguish between AGN and star-forming galaxies. This nucleus falls into the “transition” region between AGNs and H$\text{II}$ regions. This suggests that the emission has an AGN component that was diluted because of the large aperture used (∼20″) to extract the fluxes. (c) *Mid-infrared colors are redder than those of normal galaxies.* The observed IRAC colors, $[3.6] - [4.5] = +0.20 \pm 0.16$ and $[5.8] - [8.0] = +1.24 \pm 0.16$ (magnitudes in Vega system) (D. A. Dale, priv. comm.), are redder than more than 80% of normal late-type galaxies (Fig. 2; also see [8]). This is expected if there is an AGN, as AGN power-law emission falls off more slowly than galactic emission in the MIR. Thus, the IR line ratios and IRAC colors strongly argue that the source is an AGN.

**NGC 5457**

NGC 5457 is a galaxy of type Scd at a distance of approximately 7 Mpc [9]. The nucleus was classified as H$\text{II}$ by Ho et al. [4]. NGC 5457 was observed multiple times by *Chandra* for a total observing time of approximately 1 Ms (Fig. 1). For this galaxy the x-ray data by themselves provide evidence suggesting the presence of an AGN. (a) *The nucleus is an x-ray source.* (b) Even more importantly, the nuclear source is variable. The nucleus varies by about a factor of 10 over nine months (Fig. 3), with luminosity ranging from $L(0.3–8\text{keV}) \sim 3 \times 10^{37}$ to $3 \times 10^{38}$ erg s$^{-1}$. The variability rules out multiple XRBs as the origin of the x-ray emission, as they would have to be varying in
FIGURE 2. The unusually red mid-infrared color of the nucleus of NGC 3184 is marked on a Spitzer IRAC color-color diagram. The contours show the distribution of $z \sim 0$ galaxies, separated by factors of 1.8 in galaxy density. C1...C4 stand for the 3.6 $\mu$m, 4.5 $\mu$m, 5.8 $\mu$m, 8.0 $\mu$m bands respectively. The left- and right-hand concentrations are spiral and elliptical galaxies respectively. A typical error bar is shown in the lower right. (R. J. Assef 2007, priv. comm. Also see [8]). Reprinted with permission of the author.

phase. It is possible for a single XRB to produce the observed x-ray emission, but XRBs with luminosities this high are uncommon. (c) The x-ray spectrum shows an absorbed power-law with slope $\Gamma \approx 2$, similar to what is seen in AGNs. The best-fit intrinsic absorption is consistent with zero when the source is faint. (d) The ratios of 0.3–2 keV, 2–5 keV, and 5–8 keV counts for this nucleus are similar to those seen in Compton-thick AGNs [10]. Points (c) and (d) together suggest a highly obscured AGN where, like in the Seyfert galaxy NGC 1068, the dominant observed emission is radiation that has been scattered into our line of sight. Finally, (e) as can be seen in Fig. 3, the behavior of the nucleus is markedly different from that of a known star cluster of comparable x-ray luminosity which is $\sim 110$ pc away from the nucleus. This suggests the nuclear source is not simply another star cluster.

CONCLUSION

There are compelling, though not conclusive, arguments that NGC 3184 and NGC 5457 actually host AGNs even though neither shows signs of AGNs in their optical spectra. These AGNs are excellent candidates for being low-mass SMBHs, as they reside in low-mass bulges. A similar approach can be used to uncover more candidate low-mass SMBHs.

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FIGURE 3. X-ray variability of the nucleus of NGC 5457 as seen by Chandra. The filled squares show the nuclear count rate, and the open squares the count rate from a nearby star cluster. The nucleus varies by almost a factor of ten between March and November, 2004.

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