DISCOVERY OF AN ACTIVE SUPERMASSIVE BLACK HOLE IN THE BULGELESS GALAXY NGC 4561

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ABSTRACT

We present XMM-Newton observations of the Chandra-detected nuclear X-ray source in NGC 4561. The hard X-ray spectrum can be described by a model composed of an absorbed power law with $\Gamma = 2.5^{+0.3}_{-0.3}$ and column density $N_H = 1.9^{+0.1}_{-0.2} \times 10^{22}$ atoms cm$^{-2}$. The absorption-corrected luminosity of the source is $L_{\text{X}}(0.2–10.0 \text{ keV}) = 2.5 \times 10^{41}$ erg s$^{-1}$, with bolometric luminosity over $3 \times 10^{42}$ erg s$^{-1}$. Based on the spectrum and the luminosity, we identify the nuclear X-ray source in NGC 4561 to be an active galactic nucleus (AGN), with a black hole (BH) of mass $M_{\text{BH}} > 2 \times 10^4 M_\odot$. The presence of a supermassive black hole at the center of this bulgeless galaxy shows that BH masses are not necessarily related to bulge properties, contrary to general belief. Observations such as these call into question several theoretical models of BH–galaxy coevolution that are based on merger-driven BH growth; secular processes clearly play an important role. Several emission lines are detected in the soft X-ray spectrum of the source which can be well parameterized by an absorbed diffuse thermal plasma with non-solar abundances of some heavy elements. Similar soft X-ray emission is observed in spectra of Seyfert 2 galaxies and low-luminosity AGNs, suggesting an origin in the circumbulge plasma.

Key words: galaxies: active – galaxies: individual (NGC 4561) – galaxies: nuclei – X-rays: individual (NGC 4561)

Online-only material: color figures

1. INTRODUCTION

The past decade has seen extraordinary growth in our understanding of supermassive black holes (SMBHs), with secure detections, mass measurements, and new demographic information (see Ferrarese & Ford 2005 and references therein). Knowledge of the mass function of SMBHs directly affects our understanding of SMBH formation and growth, nuclear activity, and the relation of SMBHs to the formation and evolution of galaxies in hierarchical cold dark matter models (e.g., Menci et al. 2004). The cumulative mass function needed to explain the energetics of high-redshift quasars implies that all galaxies in the local universe should host an SMBH (e.g., Marconi et al. 2004; Shankar et al. 2004). Observationally, however, we do not know whether every galaxy hosts an SMBH. Traditional methods of finding SMBHs, namely stellar dynamics and gas dynamics, are powerful only at the high-mass end of the SMBH mass function; the black hole (BH) sphere of influence cannot be resolved for BH masses less than $10^6 M_\odot$ beyond a distance of a couple of Mpc, even with the Hubble Space Telescope (Ferrarese & Ford 2005). Perhaps the most efficient way of finding SMBHs in galaxies is to look for active SMBHs. In fact, looking for active galactic nucleus (AGN) activity is perhaps the only viable way to probe the low-mass end of the local SMBH mass function. X-ray observations provide the best opportunity for this purpose because X-ray emission is an ubiquitous property of AGNs, and X-rays can penetrate obscuring material that might hide an AGN at other wavelengths. Indeed, X-ray observations have detected AGN activity in what were thought to be “normal” galaxies in clusters (e.g., Martini et al. 2002) and in the field (e.g., Brand et al. 2005).

In an effort to study the demographics of local SMBHs, we undertook a Chandra program to look for nuclear X-ray sources in nearby optically “normal” spiral galaxies (within 20 Mpc). This program was highly successful; we discovered AGNs in the nuclei of what were thought to be “normal” galaxies (Ghosh et al. 2008; Ghosh 2009; see also Zhang et al. 2009; Desroches & Ho 2009). The nuclear X-ray sources, however, could have been stars, binaries, supernova remnants, or AGNs. Through extensive spectral, timing, and multiwavelength analysis we classified the nuclear X-ray sources and found 17 (out of 56 surveyed) that are almost certainly low-luminosity AGNs (LLAGNs). Thus at least 30% of “normal” galaxies are actually active. The inferred luminosities of these sources range from $10^{37.5}$ to $10^{42}$ erg s$^{-1}$. In a few objects where SMBH masses were known from stellar/gas velocity dispersion methods, we find accretion rates as low as $10^{-5}$ of the Eddington limit, comparable to what has been found in LINERS (e.g., Dudik et al. 2005).

We then expanded upon the initial Chandra survey by using the sample of SINGS galaxies (Spitzer INfrared Galaxy Survey; Kennicutt et al. 2003). Of the 75 SINGS galaxies, 60 have data in the Chandra archive and we detected nuclear X-ray sources in 36 of them (Grier et al. 2011). This once again shows that X-ray observations are far more efficient at detecting AGNs than optical observations.

As noted above, through multiwavelength analysis we have shown that a large fraction of the Chandra-detected nuclear X-ray sources are indeed AGNs. Additionally, using statistical arguments we have shown most of them to be AGNs (Ghosh 2009; Mathur et al. 2008; Grier et al. 2011). We obtained XMM-Newton spectra of several of our Chandra-detected nuclear X-ray sources with the goal of obtaining secure identifications as either AGNs or other contaminants. In this paper we focus on the bulgeless galaxy NGC 4561 for the following reason.

The mass of the SMBHs in centers of galaxies was found to be correlated with the bulge luminosity of host galaxies ($M_{\text{BH}}–L_{\text{Bulge}}$ relation; Magorrian et al. 1998; revised in Gültekin et al. 2009). Even a tighter correlation was later found between
the BH mass and the velocity dispersion ($\sigma$) of the bulge ($M_{\text{BH}}-\sigma$ relation; Gebhardt et al. 2000; Ferrarese & Merritt 2000; Merritt & Ferrarese 2001). Basically, the mass of the BH seems to be correlated with the mass of the bulge (Häring & Rix 2004). The above relations for normal galaxies also extend to active galaxies (e.g., McLure & Dunlop 2002; Woo & Urry 2002). These results were interpreted to imply that the formation and growth of the nuclear BH and the bulge in a galaxy are intimately related, and several theoretical models have attempted to explain the observed $M_{\text{BH}}-\sigma$ and $M_{\text{BH}}-L_{\text{bulge}}$ relations (e.g., Adams et al. 2001; Di Matteo et al. 2003). Hydrodynamic cosmological simulations, such as those of Hopkins et al. (2006), naturally account for BH–galaxy coevolution. In all such models, the bulge determines the nuclear BH mass. In the models of Volonteri & Natarajan (2009) seed BH masses are correlated to the host dark matter properties; these seeds could have been formed by direct collapse of pre-galactic halos (Begelman et al. 2010). Major mergers then trigger simultaneous BH growth and star formation resulting in a tight coupling between the two. A clear prediction of these models is that low-mass bulgeless galaxies today are unlikely to host nuclear BHs (Volonteri et al. 2011). Finding AGNs in bulgeless galaxies would certainly be a challenge for such models. Perhaps the BHs in bulgeless galaxies represent the seed BHs that have not yet grown. It has also been shown that the merger and SMBH growing process may not create a bulge because of star formation and, mainly, because of supernova feedback (Governato et al. 2010). Recent studies have shown that even moderate-luminosity AGNs up to $z \sim 3$ are powered mostly through internally driven processes (Mullaney et al. 2012), and that mergers do not play a major role in triggering AGNs (Cisternas et al. 2011; Schawinski et al. 2011). Thus, the role of mergers in the growth of SMBHs remains a matter of debate and SMBHs in bulgeless galaxies provide an important piece of the puzzle. Enlarging the sample of these objects is thus crucial to learn their properties and to be able to understand their formation and evolution mechanisms.

In this paper, we present XMM-Newton data of the nuclear X-ray source in the bulgeless galaxy NGC 4561, which shows evidence of being an AGN. This secure identification of an SMBH in a bulgeless galaxy shows that a bulge is not necessary for the existence of a BH and the presence of SMBHs in bulgeless galaxies is more common than expected.

2. NGC 4561

NGC 4561 (Sdm) is a late-type bulgeless spiral galaxy at $z = 0.00469$. It follows the selection criteria used in our previous Chandra survey (close to face on with inclination less than 35°) to ensure that the nuclear source is not obscured by the disk of the host galaxy; galactic latitude $|b| > 30°$ to avoid obscuration and contamination from our own Galaxy; and no known starburst or AGN activity) in which a nuclear X-ray source was detected (Ghosh 2009). The optical spectra of NGC 4561 were analyzed by Kirhakos & Steiner (1990), who classified it as an H II region-like galaxy.

The nuclear X-ray source was detected in a Chandra observation with 103 net counts with a count rate of 0.029 ± 0.003 counts s$^{-1}$. The source was found to be hard ($HR = -0.53_{-0.13}^{+0.14}$). The spectrum was fitted with a power law $\Gamma = 1.5 \pm 0.3$ and no intrinsic absorption ($N_H \leq 1.7 \times 10^{21}$ cm$^{-2}$). With this model the flux was $F(0.3–8 \text{ keV}) = 2.5 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ which corresponds to a luminosity of $L_{(0.3–8 \text{ keV})} \simeq 5 \times 10^{39}$ erg s$^{-1}$. This luminosity is a lower limit; the hardness of the source indicates that the source is likely to be absorbed. The quality of the Chandra data, however, was not good enough to determine the spectral shape accurately. The hardness of the emission and the sufficiently high luminosity make this source a good candidate AGN (Ghosh 2009).

The Chandra observations also showed a second source at 7′ from the nucleus (source B henceforth), which is soft ($HR = -0.9$), and its flux is only 10% of the nuclear source flux. Even though source B would not be resolved by XMM-Newton, its effect on the spectrum of the nuclear X-ray source should be minimal.

3. OBSERVATIONS AND DATA REDUCTION

Our target was observed with XMM-Newton on 2009 July 10. For the European Photon Imaging Camera (EPIC), the exposure times were 57022 s for MOS1, 57038 s for MOS2, and 55960 s for pn; all of these exposures were obtained using the thin filter in extended full frame.

The data were processed and filtered using SAS v9.0.0 using tasks ephchian and emchian. Before the source extraction, we applied standard and temporal filters to the event list. For the standard filter we selected the energy to be between 0.2 and 15 keV for pn and between 0.2 and 12 keV for MOS, single or double pixel events (PATTERN $\leq 4$) for pn and single, double, or triple pixel events for MOS (PATTERN $\leq 12$), with good flag values, (#XMMEA_EP) for pn and (#XMMEA_EM) for MOS. For the temporal filters we created light curves for the 10–12 keV band selecting only events with PATTERN $= 0$ (as recommended by the XMM SAS User Guide)$^6$. The good time intervals were created by rejecting the intervals with count rates higher than 0.5 counts s$^{-1}$ for pn and 0.25 counts s$^{-1}$ for MOS. The effective exposure time was 26.3 ks (for pn) corresponding to 47% of the observation time. The effective exposure times for MOS after applying the GTI were 36.7 ks (64%) for MOS1 and 37.6 ks (66%) for MOS2.

Within the circular extraction region of 20′ radius the total number of counts detected in the pn data was 6638 counts with a rate of 0.282 ± 0.004 counts s$^{-1}$. The exposure time at the source (after vignetting correction) was 21.91 ks. Our source was detected in soft and hard X-rays with 4529.4 counts (0.2–2.5 keV) and 1581.7 counts (2.5–10.0 keV), which corresponds to $HR = -0.48 \pm 0.01$. The background level was 2.13 counts pixel$^{-1}$. There were no considerable variations of the count rate during the observation.

3.1. The Spectra

For extracting the spectrum we used a selection area of a 20′′ radius circle centered at the source and selected only events with FLAG $= 0$ in order to obtain a good quality spectrum. When extracting the background spectrum we used a 41′′ side square. Finally, the RMF and ARF files were created and backscale was run. Corrections for out of time events or pile-ups were not needed.

The spectrum was analyzed using Xspec v12.6.0 (HEASOFT). We binned the spectra using grppha with a minimum of 50 counts per bin for the pn spectrum and 40 counts per bin for the MOS1 and MOS2 spectra.

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$^6$ http://xmm.esa.int/external/xmm_user_support/documentation/sas_usg/USG/
3.1.1. Checking for Possible Contamination

We checked if the spectrum was contaminated. This was a possibility given that there was a third source at 32" from the nucleus (source C here onward), which could contaminate the source spectrum. The source extraction radius of 26.65 encircles 90% of the energy, so some contamination from source C was expected. In order to see how important this contamination was, we tried different selection areas when extracting the spectrum: (1) a circle with a radius of 20" centered at the source, (2) a circle with a radius of 26.65 (which encircled 90% of the total energy), (3) the same 26.65 circle but excluding a 26.65 circle around source C, and (4) a 26.65 radius semicircle on the opposite side of source C.

These selection areas are shown in Figure 1. Emission-line-like features were present in all of the four extracted spectra, which are discussed further in Section 4. Also, all of the spectra have similar values for Γ and for the observed flux showing that the contamination is negligible, and that the emission features present in the spectrum are real.

3.1.2. The Fitting Process

The spectral fitting was performed on the pn spectrum for energies $E \geq 0.3$ keV. Because of the considerably lower signal to noise of the MOS data, it did not help to constrain the parameters any further. Once the final models were chosen, we tried them on the MOS1 and MOS2 spectrum and confirmed that they are consistent.

To fit the spectra, different models were tried, always with a fixed galactic absorption of $N_H = 2.11 \times 10^{20}$ cm$^{-2}$ and a free intrinsic absorption. Both absorption components were represented with the “wabs” model for photoelectric absorption.

First, we tried with a power law, which by itself does not provide a good fit ($\chi^2 = 1.28$ for 114 dof) and overestimates the counts for high energies. To avoid the latter issue we fitted the absorbed power law using only the hard part of the spectra ($E \geq 2.5$ keV). To obtain a good fit in the hard range of energies, intrinsic absorption is needed (as suspected from the Chandra observation). We needed another component to model the soft band, since the power law is almost completely absorbed in the soft band (see Figure 2). The resulting photon index was $\Gamma = 2.46$. From here on, when fitting the spectrum over the entire energy range, the $\Gamma$ parameter was kept frozen at this value. In order to characterize the unresolved nearby source (source B), we also added a blackbody component with a flux of $F(0.3–8$ keV$) = 2.5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ corresponding to the flux observed with Chandra and a temperature of $kT = 0.2$ keV. Both the temperature and the normalization were always fixed.

Since the hard band well fitted by a power law, our next task was to fit the soft component with different models. Because the spectrum showed “emission-like” features, we tried an absorbed “mekal” model, which characterizes emission from hot diffuse gas, but the fit was not good ($\chi^2 = 2.35$ for 112 dof, even worse than the absorbed power law with $\Delta \chi^2 = -117.3$, Figure 3).
Figure 3. Data fitted with an absorbed power law plus the diffuse thermal plasma model (“mekal”) with solar abundances and a blackbody. Contributions to $\chi^2$ are presented in the bottom panel and show that this model does not fit the data well.

(A color version of this figure is available in the online journal.)

Table 1

| Model ID | Model Component Parameters | $\chi^2$ (dof) |
|----------|---------------------------|----------------|
| 1        | Absorbed power law and thermal plasma with solar abundance | $N_H = 1.02 \pm 0.05$ | 2.35 (112) |
| 2        | Absorbed power law and thermal plasma with non-solar abundance | $N_H = 0.86 \pm 0.05, kT = 0.11 \pm 0.01$ | 2.27 (113) |
| 3        | Absorbed power law and reflection | $N_H = 1.06 \pm 0.05$ | 1.39 (113) |
| 4        | Absorbed power law and vmekal with solar abundance | $N_H = 1.02 \pm 0.05, kT = 0.12 \pm 0.01, $\text{abund} = 0.3 \pm 0.3$ | 2.53 (112) |
| 5        | Absorbed power law and vmekal with non-solar abundance | $N_H = 1.02 \pm 0.05, kT = 0.12 \pm 0.01, $\text{abund} = 0.3 \pm 0.3$ | 1.11 (107) |

Notes.

a In all models, Galactic absorption was added with $N_H = 2.11 \times 10^{20}$ cm$^{-2}$ and the photon index of the power law was $\Gamma = 2.46$ (fitting obtained only for $E \geq 2.5$ keV). These two parameters were always frozen when fitting. All the models also have a blackbody with $kT = 0.2$ keV and flux $F(0.2–10$ keV) = $2.5 \times 10^{-14}$ accounting for source B.

b All column densities are in units of $10^{22}$ cm$^{-2}$; temperatures are in keV.

This fit was done by fixing the abundance to the solar value. Leaving this parameter free does not improve the fit considerably ($\chi^2 = 2.27$ for 111 dof, Figure 4).

We also tried to fit the soft component with the “vmekal” model, the same as the “mekal” model, but allowing the abundances of each element to vary individually. A good fit was finally found using vmekal when leaving the abundances of some of the heavier elements as free parameters. This model has $\chi^2_v = 1.11$ for 107 dof (Figure 5) that corresponds to $\Delta \chi^2 = 144.43$ when compared to the fit with solar abundances.

It is possible that in the soft band we are observing the continuum reflected off some nearby scattering material. For this reason, we also tried the “reflionx” model (reflection by a constant density illuminated atmosphere). This model does reproduce some emission lines, but the fit is not good and it is also a worse fit than the absorbed power law ($\chi^2_v = 1.39$ for 113 dof, $\Delta \chi^2 = -11.18$ when compared to the absorbed power-law model, Figure 6).

4. RESULTS

The results of the spectral fitting are presented in Table 1. The best-fit model is composed of an absorbed power law with $\Gamma = 2.5^{+0.4}_{-0.3}$ and $N_H = 2.0^{+0.3}_{-0.2} \times 10^{22}$ cm$^{-2}$ and an absorbed thermal plasma component with non-solar abundances for some of the heavy elements (O = 3.3^{+0.14}_{-0.12}, Na = 34^{+8}_{-12}, Si = 0^{+0.2}_{-0.3}, Fe = 0.12^{+0.06}_{-0.04}, Ni = 0^{+0.4}_{-0.2}). We assume a temperature of $kT = 0.39^{+0.11}_{-0.03}$ keV and $N_H = 7^{+4}_{-2} \times 10^{20}$ cm$^{-2}$ (and a blackbody for source B). The fit to the spectrum is presented in Figure 5 and the corresponding theoretical model in Figure 7. The observed flux is $F(0.2–10$ keV) = $1.2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ which corresponds to a luminosity of $L(0.2–10.0$ keV) = $5.8 \times 10^{38}$ erg s$^{-1}$.
therefore about $3.2 \times 10^{40}$ erg s$^{-1}$. The unabsorbed luminosity is $L(0.2–10.0 \text{ keV}) = 2.5 \times 10^{41}$ erg s$^{-1}$. The bolometric luminosity of the source is therefore about $3.5 \times 10^{42}$ erg s$^{-1}$ (assuming a bolometric correction factor of 14 for this luminosity; Vasudevan & Fabian 2007), putting it squarely in the luminosity range observed for AGNs.

5. DISCUSSION

The hard-band spectrum of the nuclear X-ray source in NGC 4561 can be described as a power law with photon index $\Gamma = 2.5^{+0.4}_{-0.3}$. Most of the soft component of the power law is absorbed (intrinsic absorption of $N_H = 2.0^{+0.3}_{-0.2} \times 10^{22} \text{ cm}^{-2}$). The source shows a hardness ratio of $HR = -0.48 \pm 0.01$ and an absorption-corrected luminosity of $L(0.2–10.0 \text{ keV}) = 2.5 \times 10^{41}$ erg s$^{-1}$. The photon index and the high luminosity of the source are indications of the presence of an active SMBH in the center of NGC 4561.

The soft emission can be modeled as an absorbed thermal plasma with $kT = 0.59^{+0.04}_{-0.05} \text{ keV}$ and non-solar abundances as follows: O $= 0.33^{+0.14}_{-0.12}$, Na $= 34^{+11}_{-8}$, Si $\leq 0.2$, Fe $= 0.12^{+0.06}_{-0.04}$, and Ni $\leq 0.4$, with 1.0 corresponding to the solar values.

No other model was capable of providing a good fit for the spectrum. It is quite interesting that non-solar abundances are required for some elements. The nickel abundance is consistent with the solar value within the 3σ contour. For oxygen, sodium, silicon, and iron the abundances are not consistent with the solar values, as can be seen in the contour plots (Figures 8–11 for O, Na, Si, and Fe, respectively); they are sub-solar for oxygen,
Figure 6. Spectrum fitted with an absorbed power law plus an ionized reflection component. Contributions to $\chi^2$ are presented in the bottom panel. This model does not provide a good fit.

(A color version of this figure is available in the online journal.)

Figure 7. Theoretical model of the best-fit spectrum showing the different components (absorbed power law, absorbed thermal plasma, and blackbody).

silicon, and iron but super-solar for sodium. It is important to note that when these parameters are kept frozen at solar value the model does not provide a good fit. Different abundances for different elements suggest that the observed thermal plasma is not well mixed in heavy elements or that the models we use are too simplistic to describe its physical conditions.

Abundances for some elements in AGNs have been measured before, for example in Mrk 1044 and Mrk 279, where super-solar abundances for C, Ni, O, and Fe were found (Fields et al. 2005; Fields et al. 2007). Hamann & Ferland (1999) found that high-redshift quasars also have super-solar metallicities. Later studies showed that quasars have super-solar abundances at all redshifts (Hamann & Simon 2010) which would be consistent with the scenario of AGNs appearing after an important star formation event. Sub-solar abundances, however, have been observed in the vicinity of AGNs, as in the spectrum of NGC 1365 (Guainazzi et al. 2009) that shows sub-solar abundances of carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron. Sub-solar abundances were also inferred for the sample of LLAGNs, LINERs, and starburst galaxies presented in Ptak et al. (1999).

The temperature for the thermal plasma, $kT = 0.59^{+0.04}_{-0.05}$ keV, is similar to what has been found in objects such as NGC 3367 and NGC 4536 ($kT = 0.64 \pm 0.03$ keV and $kT = 0.58 \pm 0.03$ keV, respectively; McAlpine et al. 2011), and is in agreement with what is expected for LLAGNs; $kT \approx 0.4$–0.8 keV (Ho 2008).

Levenson et al. (2001) have analyzed ROSAT and ASCA data of Seyfert 2 galaxies with starbursts, and found that most of the soft emission, which is modeled with a thermal component, is
produced by star formation. The median temperature of this component for their sample is about 0.6–0.7 keV. In their analysis, solar abundances were used because the quality of the data would not allow a measure of metallicity, but they do mention that low abundances are required in high-resolution spectra of starburst galaxies as shown by Dahlem et al. (1998). Given the similarity of the temperature of the thermal component and the sub-solar abundances of NGC 4561 that we find, the soft X-ray emission we observe could be produced by nuclear star formation.

No variability was observed during the observation but there was a variation between the Chandra observation on 2006 March 15 and our XMM-Newton observation. From the count rate observed on Chandra (0.029 counts s\(^{-1}\)), PIMMS predicts a count rate of 0.072 counts s\(^{-1}\) for XMM-Newton pn using the thin filter and the whole point-spread function (PSF) (∼5 arcmin). We expected a more realistic value of about 78% of this rate, given the smaller (20′ radius) PSF we used; it corresponds to 0.056 counts s\(^{-1}\). Our observed count rate of 0.282 ± 0.004 counts s\(^{-1}\) was five times higher than expected. This variation might have resulted from the change in the absorber column density. The variability also supports the AGN scenario.

A lower limit on the BH mass can be obtained assuming that the BH radiates at Eddington luminosity; for \(L_{\text{bol}} = \)

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Figure 10. $\chi^2$ contours for the abundance of silicon and temperature of the plasma in the best-fit model (solar abundance is 1). Sub-solar silicon is clearly indicated. (A color version of this figure is available in the online journal.)

Figure 11. $\chi^2$ contours for the abundance of iron and temperature of the plasma in the best-fit model (solar abundance is 1). Again, sub-solar iron abundance is required by the fit. (A color version of this figure is available in the online journal.)

3 $\times 10^{42}$ erg s$^{-1}$, the BH must have a mass $M_{\text{BH}} > 2 \times 10^4 M_\odot$. This is an exciting discovery of an SMBH in a bulgeless galaxy. To our knowledge, two bulgeless galaxies are known to host AGNs from optical studies: NGC 4395 (Sdm; Filippenko & Sargent 1989; Peterson et al. 2005) and NGC 1042 (Scd; Shields et al. 2008). Both galaxies host a nuclear star cluster. IR spectroscopy with Spitzer led to the discovery of AGNs in two more Sd galaxies, NGC 3621 (Satyapal et al. 2007) and NGC 4178 (Satyapal et al. 2009). These two also harbor a nuclear star cluster. Using XMM-Newton, two other AGNs in bulgeless galaxies have been confirmed by McAlpine et al. (2011), one in NGC 3367 (Sc) and the other in NGC 4536 (SAbc). We found nuclear X-ray sources in M101 (type Scd), NGC 4713 (Sd), NGC 3184 (Scd), and NGC 4561 (Sdm) (Ghosh et al. 2008; Ghosh 2009) and argued that they are likely to be AGNs. The dwarf starburst galaxy Henize 2-10 is also very likely to host an AGN (Reines et al. 2011). In this paper, we present conclusive evidence that NGC 4561 does in fact host an AGN. The discovery of SMBHs in the nuclei of these galaxies calls into question whether the masses of SMBHs are governed by bulge properties (Section 1). These results suggest that SMBHs in bulgeless galaxies are far more common than we previously thought, in clear disagreement with some models of BH growth. A key prediction of the models of Volonteri
& Natarajan (2009) is that low-mass bulgeless galaxies today are unlikely to host nuclear BHs, which does not seem to be the case. While BHs grow through merger-driven processes, alternative tracks of BH growth must exist; secular process appear to play an important role.

About 75% of late-type galaxies host nuclear star clusters (Böker et al. 2004). Is the SMBH then related to the mass of the star cluster (Seth et al. 2008) or the dark matter halo (Baes et al. 2003)? Are the BHs in bulgeless galaxies the seed BHs at high redshift that did not grow? Answering these kinds of questions is fundamental to our knowledge of BH–galaxy formation and coevolution.

6. CONCLUSIONS

We present an XMM-Newton spectrum of the Chandra-detected nuclear source in NGC 4561 and show that it is an obscured AGN. The existence of nuclear SMBHs in bulgeless galaxies shows that BH masses are not governed by bulge properties. This calls into question several theoretical models (Section 1) of BH–galaxy coevolution which are merger-driven; secular processes clearly play an important role in BH growth.

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