Discovery of an Active Intermediate-mass Black Hole Candidate in the Barred Bulgeless Galaxy NGC 3319

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Abstract

We report the discovery of an active intermediate-mass black hole (IMBH) candidate in the center of nearby barred bulgeless galaxy NGC 3319. The point X-ray source revealed by archival Chandra and XMM-Newton observations is spatially coincident with the optical and UV galactic nuclei from Hubble Space Telescope observations. The spectral energy distribution derived from the unresolved X-ray and UV-optical flux is comparable with active galactic nuclei rather than ultraluminous X-ray sources, although itsbolometric luminosity is only $3.6 \times 10^{40}$ erg s$^{-1}$. Assuming an Eddington ratio range between 0.001 and 1, the black hole mass ($M_{\text{BH}}$) will be in the range $3 \times 10^{5} - 3 \times 10^{6} M_{\odot}$, placing it in the so-called IMBH regime and making it possibly one of the lowest reported so far. Estimates from other approaches (e.g., fundamental plane, X-ray variability) also suggest $M_{\text{BH}} \lesssim 10^{5.5} M_{\odot}$. Similar to other BHs in bulgeless galaxies, the discovered IMBH resides in a nuclear star cluster with mass of $\sim 6 \times 10^{6} M_{\odot}$. The detection of such a low-mass BH offers us an ideal chance to study the formation and early growth of SMBH seeds, which may result from the bar-driven inflow in late-type galaxies with a prominent bar such as NGC 3319.

Key words: galaxies: active – galaxies: individual (NGC 3319) – galaxies: nuclei

1. Introduction

It is widely believed that supermassive black holes (SMBHs) with masses of $10^{5-10} M_{\odot}$ are present in most (possibly all) galaxies with massive bulges, and the BH mass correlates tightly with various classical bulge properties (see Kormendy & Ho 2013 for a review). These black holes must be grown from much smaller “seeds”. Intermediate-mass black holes (IMBHs) in nearby galaxies, with masses in the range of $10^{2-6} M_{\odot}$, provide important clues to the mass and abundance of these seeds in the early universe (see the review by Greene 2012). IMBHs also bridge the gap between SMBHs in galactic nuclei and stellar black holes in binaries. Apparently, IMBHs are much more difficult to find because the radii of their gravitational influence are too small to be resolved spatially even in nearby galaxies. An alternative approach is to search for dwarf active galactic nuclei (AGNs), and hitherto discovers hundreds of candidates with BH masses of $10^{3-6} M_{\odot}$ (Greene & Ho 2007; Dong et al. 2012b; Reines et al. 2013; Lemons et al. 2015; Mezcua et al. 2016, 2018; Pardo et al. 2016; Liu et al. 2018).

In the hierarchical framework of galaxy formation and evolution, the correlation between SMBHs and galactic bulges is regulated by the major merger processes. A related issue is the observational census of black holes in late-type spirals and particularly whether SMBHs can form in galaxies that lack bulges, which have not undergone violent evolution by major merger. The stellar dynamical constraints on the presence of the BH in Local Group bulgeless galaxy M33 shows that it does not contain an SMBH with an extremely tight upper limit of $M_{\text{BH}} \lesssim 1500-3000 M_{\odot}$ (Gebhardt et al. 2001). Again, evidence that BHs can occur in at least some very late-type disk galaxies comes from the detection of a small number of AGNs in Scd and Sd-type spirals. The first and most well-studied BH evidence in a bulgeless galaxy is NGC 4395 (Filippenko & Sargent 1989; Filippenko & Ho 2003), which is a dwarf Sdm galaxy with hallmark signatures of a type 1 AGN (Filippenko & Sargent 1989; Filippenko & Ho 2003) such as broad emission lines (Filippenko & Sargent 1989) and rapid X-ray variability (Iwasawa et al. 2000). An ultraviolet (UV) reverberation-mapping measurement gave $M_{\text{BH}} = (3.6 \pm 1.1) \times 10^{5} M_{\odot}$ (Peterson et al. 2005), which is verified by recent direct dynamical measurements (den Brok et al. 2015). Additional evidence in other bulgeless galaxies has been reported in recent years (e.g., Satyapal et al. 2007, 2009; Shields et al. 2008; Secrest et al. 2012). Instead of bulges, nature seems usually to create far more compact nuclear star clusters (NSCs) at the centers of very late-type spirals (e.g., Böker et al. 2002), with the size of globular clusters but 10 times greater mass. It is notable that the discovery of an AGN in a bulgeless galaxy is nearly always accompanied by an NSC (e.g., Filippenko & Ho 2003; Shields et al. 2008; Barth et al. 2009; Secrest et al. 2013). However, the connection between NSCs and BHs, their link to galaxy formation, and their evolution, are still poorly understood.

In this paper, we report the discovery of an IMBH candidate in the center of NGC 3319, which is a nearby barred bulgeless galaxy (see its SDSS image in the left panel of Figure 1). This target was first noted by our cross-match between...
XMM-Newton (XMM for short) serendipitous catalog and nearby late-type galaxies. Recent Chandra observations pinpoint the X-ray source to the galaxy center. We adopt the luminosity distance (14.3 Mpc) determined from Cepheid variable stars (Sakai et al. 1999). The physical scale at the distance is 69 pc/arcsec.

2. Data and Analysis

2.1. X-Ray Observations

NGC 3319 was observed by Chandra on 2017 January 16 (observation ID 19350, PI: McHardy) for an exposure of 10 ks, using the back-illuminated chips of the Advanced CCD Imaging Spectrometer (ACIS-S). The galaxy was placed at the aimpoint of the S3 chip. The data were processed with the CIAO (version 4.9) and CALDB (version 4.7.7), following standard criteria. New level 2 event files were created using the chandra_repro script in CIAO. We ran the automated point-source detection tool wavdetect on 0.3–8 keV images of the S3 chip and found a point-like X-ray source that is spatially coincident with the optical nucleus of NGC 3319 (see details in Section 3.1). Taking it as the source position, we extracted the source spectrum in the 0.3–7.0 keV range from a circular region with a radius of 2″5. The background spectrum was estimated in an annulus region centered on the source position, with an inner radius of 4″ and outer radius of 7″, respectively. We also checked that no background flaring events occurred during the observation. There are 61 net counts in total detected in the energy band of 0.3–7 keV, but most (50/61) are in 1–5 keV. Utilizing the same extraction regions as were used for the spectral analysis, a background subtracted light curve was created using the dmextract tool in CIAO. We have also noted that NGC 3319 is serendipitously detected by XMM as a point source on 2004 August 24 with an effective exposure time of 10 ks, and the position is consistent with Chandra within ~0″5. We extracted counts from a circle with radius of 40″ centered on the source, and the background is estimated from three circles with radii 30″–40″ around the source. The extracted X-ray spectrum and light curves are presented in Figure 2.

We have tried to perform a joint fit to the XMM and Chandra spectrum simultaneously. Due to the small number of source counts, the spectrum was rebinned to at least five counts in each energy bin for XMM and two counts for Chandra. The spectral fitting was performed using XSPEC with Cash-statistic in the minimization instead of \( \chi^2 \). We fitted the spectrum with an absorbed power-law model \((phabs * zphabs * zpowerlaw)\), in which \( phabs \) is the Galactic absorption that is fixed in the fits. The model gives a photon index \( \Gamma = 2.02 \) (1.60–2.50 in 90% confidence ranges) and an intrinsic absorption column density \( N_H = 0.8 \times 10^{21} \text{cm}^{-2} \). The unabsorbed 2–10 keV flux for the Chandra observation is 4.3 (3.4–5.6) \( \times 10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2} \), corresponding to a luminosity of 1.0(0.8–1.4) \( \times 10^{39} \text{ erg s}^{-1} \). Note that the XMM luminosity is higher by a factor of ~1.5, but is consistent with the Chandra luminosity within the errors. We will adopt the Chandra result in the analysis below since it has better resolution.

2.2. HST Observations

NGC 3319 has been observed by Hubble Space Telescope (HST) Wide Field and Planetary Camera 2 (WFPC2) over a two-month period (1997 November 11 to 1998 January 3), including 13 epochs of F555W and 4 epochs of F814W exposures. Before that, it has been targeted in the F606W filter on 1994 October 19 and in UV (F220W) by Faint Object Camera (FOC) on 1993 March 15.

2.2.1. UV Image

The UV image of NGC 3319 was observed as part of the project to search for low-luminosity AGNs that appear as unresolved UV point sources in the nuclei of galaxies down to resolution ~0″05 with pre-COSTAR HST/FOC (Proposal ID: 4804). A compact source is embedded in the elongated diffuse emission along with the bar, which was first noticed as unresolved by Maoz et al. (1996). To check it and measure
In order to depict the nuclear excess in a more self-consistent way, we then performed GALFIT decomposition by adding an unresolved PSF component. We start with the PSF + King + Sérsic model. The fitting has improved a lot (with reduced $\chi^2$ changed from 1.12 to 1.07) and yielded smooth residuals at both small and large scales (see top panels of Figure 4). Given a zeropoint of 20.64 in the ST magnitude system, the fitted magnitudes of the PSF and King component are 18.70 ± 0.01 and 18.17 ± 0.03, corresponding to $(1.33 \pm 0.03) \times (2.17 \pm 0.09) \times 10^{-16}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$, respectively. To test whether the magnitudes are model dependent, we then try the PSF+2-Sérsic model, that is to fit the NSC with a Sérsic component (e.g., Carson et al. 2015) instead of a King profile. The fitting yields slightly larger residuals but has a similar PSF magnitude of 18.66 ± 0.01, which is 0.04 mag offset from the King model. We take the offset as the uncertainty of the PSF component. The final best-fit parameters are presented in Table 1.

We have also tried the PSF model created by Tinytim (Krist 1995), which considers the spherical aberration, and obtained comparable results yet with larger residuals in the central part than empirical star PSF.

### 2.2.2. Optical Image

The step-by-step decomposition is not trivial for WFPC2 optical images. First, the resolution in the optical is lower than the UV, particularly considering that the center of NGC 3319 is located in the WF4 camera ($0''1$/pixel) and thus severely undersampled. Moreover, the F555W and F814W images are all saturated in the central part, but the fact itself indicates a bright nucleus. The F606W image is the only unsaturated optical image because of a shorter exposure time. For ease of rejecting cosmic rays, the observation was split into two equal exposures of 80 s each. The two single exposures were then combined, resulting in a cosmic-ray cleaned image ready for further GALFIT fitting. Following our previous work with F606W imaging decomposition (Jiang et al. 2013), we used the modeled PSF generated by Tinytim.

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**Figure 2.** Left: Chandra and XMM spectrum of NGC 3319, along with the best-fit models as described in Section 2.1. The inset panel shows the $\chi^2$ contours of the photon index vs. $N_{\gamma}$ at the 68%, 90%, and 99% confidence levels (from the inside out). The data-to-model ratio is shown in the lower panel. Right: Chandra and XMM light curve of NGC 3319 with a bin size of 500s.
The same model that was used for the UV band is exploited in the fitting and yields a fairly good result (see bottom panel of Figure 4). The PSF and NSC magnitudes given by the GALFIT fitting are 20.14 ± 0.01 and 18.89 ± 0.02, respectively.

2.3. SDSS Spectrum

The center of NGC 3319 was spectroscopically observed by SDSS on 2004 January 29 with an exposure time of 2500 s. We fit the spectrum with the BC03 stellar population model (Bruzual & Charlot 2003) using the STARLIGHT code (Cid Fernandes et al. 2005). During the fitting, we masked out all the prominent emission line regions. The fitted starlight model matches both the continuum and most of the main absorption lines well, and no extra non-stellar component is needed. After subtracting the stellar population model from the raw spectra, no evident broad emission lines are visible but weak narrow emission lines of H β, [O III], Hα and [N II] are detectable in the residual spectrum (see Figure 5). We measure the flux of each emission line with a single Gaussian model.

The BPT line-ratio diagram (Baldwin et al. 1981) is commonly adopted to discriminate between AGN and SF activity. NGC 3319 is located at the star-forming region of the BPT diagram basing on the fitted line fluxes, yet it has large uncertainty. The absent AGN signature can be explained by the overwhelming dominance of the stellar light in the SDSS spectrum, which was acquired by a fiber with an aperture of 3″. We have integrated the flux within SDSS fiber from the...
have obtained a much more compact NSC with $r_C \sim 9$ pc and $M_{\text{NSC}} \sim 1.6 \times 10^6 \, M_\odot$ (Georgiev et al. 2016). The discrepancy can be addressed as they have not set the PSF component in their fitting, which will force the NSC to match the central unresolved component.

3. The Nature of the Unresolved Nuclear Emission

3.1. Coincidence of the X-Ray and Optical/UV Point Source

The X-ray luminosity ($\sim 10^{39}$ erg s$^{-1}$) revealed by XMM-Newton and Chandra observations cannot immediately tell us the nature of the source, e.g., an ultraluminous X-ray source (ULX) powered by X-ray binaries (XRBs) or a low-luminosity AGN. ULXs are usually defined as point-like sources within the optical extent of a host galaxy but away from the nucleus in order to exclude AGNs (see review by Kaaret et al. 2017).
Several different isotropic X-ray luminosity thresholds have been used to classify ULXs, such as the Eddington limit for a 1.4 $M_\odot$ neutron star (Makishima et al. 2000) or simply $1 \times 10^{39}$ erg s$^{-1}$ (e.g., Swartz et al. 2011). First, we explore the possibility of XRBs by virtue of the scaling relations between the X-ray emission from XRBs and star formation rate (SFR). Using the recent formalism given by Lehmer et al. (2016) and global SFR of NGC 3319 (Zhou et al. 2015), we find that the expected global X-ray luminosity from high-mass XRBs is $2.0 \times 10^{39}$ erg s$^{-1}$, which is five times lower than the observed value. If we only care about the bar SFR, the predicted X-ray luminosity would be further lowered by one order of magnitude.

Second, the X-ray source position is exactly at or extremely close to the galactic center. The Chandra X-ray source coordinate is R.A. = 10:39:09.446, decl. = +41:41:12.10, which is 0$''$.16 away from the optical center given by NED. The UV center given by HST/FOC image is R.A. = 10:39:09.401, decl. = +41:41:11.91, which is 0$''$.54 from the X-ray position (see right panel of Figure 1) yet still within the pointing error due to the guide star position uncertainty (1$''$). We have also checked the high-resolution optical center by HST images and found that they are all consistent with each other when taking the errors into consideration. Hence, under current astrometric accuracy, the X-ray point source is highly consistent with the optical and UV galactic center, which is not in favor with the ULX scenario, since ULXs are defined as off-nucleus. On the other hand, according to the statistics on local ULX number density, ULXs are detected at rates of one per $3.2 \times 10^{10}$ $M_\odot$, one per $\sim0.5 M_\odot$ yr$^{-1}$ star formation rate (Swartz et al. 2011). This predicts a chance of $<10^{-4}$ of finding a ULX in the circle of Chandra resolution.

3.2. Spectral Energy Distribution (SED): Consistent with High-accretion-rate AGNs

Once both the unresolved optical-UV and X-ray radiation are convincingly assumed to originate from the same source, we can try to explore its nature by SED characteristics. First, ULXs usually do not show or have very weak optical counterparts. The absolute magnitudes of well-studied ULX optical counterparts are all fainter than $M_V \approx -8$, with a median magnitude of $-6$ (Vinokurov et al. 2018). Our GALFIT fitting of F606W image (roughly V-band) gives a PSF magnitude of $-10.67$, which is significantly more luminous than normal ULXs. Furthermore, the X-ray-to-optical-flux ratio, defined as $\log(f_X/f_V) = \log f_X + m_v/2.5 + 5.37$ (Maccacaro et al. 1982), where $f_X$ is the 0.3–3.5 keV observed flux in erg s$^{-1}$ cm$^{-2}$ and $m_v$ is the visual magnitude, can be used to distinguish AGN, BL Lac objects, and XRBs (Stocke et al. 1991). The calculated $\log(f_X/f_V)$ of NGC 3319 is 0.25, which is apparently lower than usual ULXs with ratio $>2$ (Tao et al. 2011). Hence, both the position and the bright optical counterpart of the nuclear source are inconsistent with the ULX scenario.

It is well known that the SED of luminous Seyfert galaxies and quasars is characterized by a big blue bump in the optical and UV bands, which is thought to be thermal emission from an optically thick accretion disk extending to a few gravitational radii (e.g., Shields 1978; Malkan & Sargent 1982). This is also the case for the optical-UV-X-ray SED of NGC 3319 nucleus (see Figure 6). Such an SED is very close to that of high accretion rate AGN systems ($\log(L/L_{\text{Edd}}) > -1.0$ in Ho 2008), but very different from those of low accretion rate...
systems in nearby low-luminosity AGNs (Ho 1999, 2008). In addition, the ratio of the optical-to-X-ray flux (αox) is usually exploited by the AGN community, specifically via the balance of energy coming out in the optical/UV emerging from the accretion disk as compared with the X-ray luminosity from the corona (e.g., Tananbaum et al. 1979). We adopt the universal definition αox = −0.3838 log f_{2500 Å} f_{2 keV}, where f_c ∝ ν^{αox} is the specific flux. Hence, it gives αox = −1.40 ± 0.05, in which f_{2500 Å} is derived from the F220W flux assuming a spectral index −1.5 and the f_{2 keV} is from Chandra. The calculated αox has well fallen in the range of AGNs including IMBHs (Dong et al. 2012a; Baldassare et al. 2017; Liu et al. 2018), and suggests a central BH accreting system.

3.3. BH Mass Estimate

The M_{BH} of type 1 AGNs are usually computed by the empirical formula under the assumption of virial equilibrium of broad-line region gas (e.g., Greene & Ho 2005). Unfortunately, the SDSS spectrum of NGC 3319 is totally dominated by starlight and no broad Ha or H β line is present. To catch sight of the AGN activity (such as potential broad lines) of such a small BH, further high-resolution spectra beyond seeing-limited observations (e.g., by HST or ground-based telescopes with adaptive optics) are probably required. Nevertheless, we can still try to estimate the M_{BH} by some other means.

Despite only a sparse sampling of the AGN SED of NGC 3319 being available (see Figure 6), it should still offer a more reliable measurement of the bolometric luminosity (L_{bol}) of the system than any estimate based on a single band. We have first scaled the median radio-quiet quasar SED of Elvis et al. (1994) to the Chandra X-ray luminosity and then integrated the entire SED. The resulting L_{bol} is ∼3.6 × 10^{40} erg s^{-1}. If we scale the quasar SED to the optical or UV luminosity, the difference of the L_{bol} is not greater than 0.1 dex. Interestingly, the L_{bol} of NGC 3319 is similar to NGC 4395 (Peterson et al. 2005) yet their SEDs are clearly different from one another. The SED of NGC 4395 shows no big blue bump with αox = −0.97, and its L_{bol}/L_{Edd} is estimated to be down to 1.2 × 10^{-3} (Moran et al. 1999; Dewangan et al. 2008). In contrast, the SED of NGC 3319 agrees with a typical quasar. Besides, the L_{bol}/L_{Edd} is found to be moderately correlated with a hard X-ray photon index (Γ) in radio-quiet AGNs. Using the correlation given by Shemmer et al. (2008), we obtained a L_{bol}/L_{Edd} of 0.26 yet with an error as high as one dex. Assuming an Eddington ratio of 0.1, the M_{BH} of NGC 3319 will be 3 × 10^{4} M_{☉}, in the regime of an IMBH. As a conservative estimate of uncertainty, allowing the Eddington ratio in the range of 0.001 to 1.0, we estimate the BH mass in the range of 3 × 10^{2} to 3 × 10^{5} M_{☉}.

It is widely known that in AGNs and BH XRBs, there is a tight correlation among their radio luminosity (L_{R}), X-ray luminosity (L_{X}) and M_{BH}—the so-called “fundamental plane” (FP) of BH activity. Therefore, the FP could be adopted as an alternative to derive M_{BH} when both the X-ray and radio luminosity are available. The recent high-resolution (<0.2") 1.5 GHz radio image of NGC 3319 yields non-detection with an upper-limit core luminosity of 10^{34.84} erg s^{-1} (Baldi et al. 2018). Taking advantage of the FP embodying low-mass BHs (Qian et al. 2018), the M_{BH} in NGC 3319 would be <10^{5} M_{☉}, which is consistent with the result above.

We have also tried to estimate the M_{BH} by X-ray variability. The excess variances of Chandra and XMM light curves are σ_{rms}^2 = 0.093 ± 0.088 and σ_{rms}^2 = 0.001 (with a 1σ upper limit 0.067), respectively. We note that the value measured from Chandra is broadly consistent with that from XMM within errors. Although with a large scatter, we estimated the M_{BH} from the σ_{rms}^2 from the Chandra data, using the relation derived by Pan et al. (2015) for low-mass AGNs, yielding M_{BH} ∼ 1.5 × 10^{5} M_{☉}. The M_{BH} of NGC 3319 is well constrained to be at the low end of the central BHs, likely <10^{5} M_{BH} based on various means above, even if the precise mass is difficult to measure for the time being.
Comparison with Other Well-known IMBHs

| Galaxy       | Distance | $L_{2-10\text{keV}}$ | $L_{\text{bol}}$ | $c_{\text{acc}}$ | $L_{\text{bol}}/L_{\text{Edd}}$ | $M_{\text{BH}}$ | Host Type      | Reference       |
|--------------|----------|-----------------------|-------------------|-------------------|-------------------------------|----------------|----------------|----------------|
| NGC 4395     | 4.2      | $2.3 \times 10^{40}$  | 5 $\times 10^{40}$ | 0.97              | $1.2 \times 10^{-4}$          | $4.3 \times 10^5$ | dwarf irregular | Filippenko & Ho (2003) |
| POX 52       | 9.3      | $4.1 \times 10^{44}$  | 1.3 $\times 10^{44}$ | 1.44              | 0.2-0.5                      | (2.2-4.2) $\times 10^8$ | dwarf elliptical | Barth et al. (2004) |
| Henize 2–10  | 9        | 2.7 $\times 10^{39}$  | 2.7 $\times 10^{40}$ | ...               | $10^{-3}$                    | $\sim 10^6 H_0$ | dwarf starburst | Reines et al. (2011) |
| UM 625       | 109      | 6.5 $\times 10^{40}$  | (0.5-3) $\times 10^{43}$ | 1.72              | 0.02-0.15                    | 1.6 $\times 10^8$ | Pseudobulge S0 | Jiang et al. (2013) |
| RGG 118      | 106      | 4.0 $\times 10^{39}$  | 4 $\times 10^{40}$  | ...               | $\sim 0.01$                   | $\sim 5 \times 10^7$ | dwarf disk      | Baldassare et al. (2015) |
| NGC 4178     | 16.8     | 8.6 $\times 10^{39}$  | 9.2 $\times 10^{42}$ | ...               | $\sim 0.2$                   | (1-10) $\times 10^4$ | barred bulgeless | Secrest et al. (2012) |
| NGC 3319     | 14.3     | 1.0 $\times 10^{39}$  | 3.6 $\times 10^{40}$ | 1.40              | $\sim 0.1$                   | 3(0.3-300) $\times 10^3$ | barred bulgeless | This work |

Note. Column (1): object Name. Column (2): luminosity distance in unit of Mpc. Column (3): X-ray luminosity integrated from 2 to 10 keV. Column (4): bolometric luminosity in unit of erg s$^{-1}$. Column (5): $c_{\text{acc}}$. Column (6): Eddington ratio. Column (7): estimated $M_{\text{BH}}$ in unit of $M_\odot$. Column (8): host galaxy type. Column (9): the literature that reports the discovery of the IMBH. For the two extensively studied IMBH prototypes NGC 4395 and POX 52, we have adopted the most updated parameters. For instance, the $M_{\text{BH}}$ of NGC 4395 is measured from the gas dynamic modeling (den Brok et al. 2015).

4. Discussions

4.1. The Uniqueness of the IMBH in NGC 3319

Our rough mass estimation of the IMBH in NGC 3319 may be down to $\sim 10^4 M_\odot$, which is possibly lower than any other known BHs found in the center of galaxies (e.g., Secrest et al. 2012; Baldassare et al. 2015), promoting the accumulated IMBH population a step closer to the stellar mass BHs. The discovery of such a low-mass BH is extremely rare and its success is owed to the particularities of NGC 3319 by comparing with other well-known IMBHs (see a summary of their properties in Table 2).

First, NGC 3319 is one of the most nearby IMBHs. The distance effect operates not only in the brightness but also the physical size resolving ability. Even at HST resolution level, the structural decomposition of AGN and starlight is not an easy job for more distant sources, particularly when considering cases of coexistence of BH and NSCs (e.g., Shu et al. 2017). Only with the aid of HST UV and Chandra X-ray imaging, which have the best resolution currently available, does the SED of the unresolved AGN component become obtainable, which then places strong constraints of its accretion rate. Hence, our discovery also implies that a joint UV/X-ray survey of late-type galaxies may be very efficient to detect low-mass BHs. Comparing with the pure X-ray survey (e.g., She et al. 2017), the added UV band can help us diagnose its accretion state and the ULX possibility. Second, the $L_{\text{bol}}$ of NGC 3319 is the faintest among all sources in question. Although it is comparable with NGC 4395, its seemingly higher $L_{\text{bol}}/L_{\text{Edd}}$ results in a lower $M_{\text{BH}}$. RGG 118 is the closest source to NGC 3319 in terms of $L_{\text{bol}}$ and $L_{\text{bol}}/L_{\text{Edd}}$, whose $M_{\text{BH}}$ is probably the lowest derived from the broad Hα line (Baldassare et al. 2015). Last but not least, the barred bulgeless host of NGC 3319 is also very distinguishing. The most analogous previously known object is NGC 4178, which also contains an NSC and is located at a similar distance, but with an $L_{\text{bol}}$ two orders of magnitudes higher. The absence of a notable bulge also reduced the starlight contamination to recognize the signal from AGN.

As a brief summary, the BH in the center of NGC 3319 is a unique IMBH in terms of its close distance, low luminosity, high accretion rate, bulgeless host, and, most interestingly, its low BH mass. Further observations are highly encouraged to obtain a more precise $M_{\text{BH}}$.

4.2. Implications for the Formation and Growth of IMBHs

Galactic nuclei typically host either an NSC (prevalent in late-type galaxies) or an SMBH (common in early-type galaxies), among which the most intriguing observations is the coexistence of NSC and SMBH in some galaxies. Ferrarese et al. (2006) has introduced the term central massive object (CMO) to unify the BH and NSC and suggest that the formation and evolution of both types of central mass concentration may be linked by similar physical processes. As we have mentioned in the introduction, the central BHs discovered in late-type galaxies are often associated with an NSC, which is exactly the case of NSC 3319. Such systems are undoubtedly very valuable for us to probe the formation of seed BH and the NSC.

As a well-known rule of thumb, we know that the mass ratio between SMBHs and classical bulges is $\sim 0.2\%$ (e.g., Marconi & Hunt 2003, see a more comprehensive review in Kormendy & Ho 2013). Assuming an Eddington rate of 0.1, we get $M_{\text{BH}} \sim 3 \times 10^3 M_\odot$, which is 0.05% of the $M_{\text{NSC}}$, slightly lower than the relation found for classical bulges. On the other hand, it is proposed that similar scaling relations are also hold between $M_{\text{NSC}}$ and their host galaxy stellar mass ($M_{\text{gal}}$), albeit it is hotly debated what is the physical mechanism setting the correlation (e.g., Ferrarese et al. 2006; Georgiev et al. 2016). Given the $M_{\text{gal}} = 3.1 \times 10^9 M_\odot$ (Georgiev et al. 2016), the $M_{\text{NSC}}$ is only 0.18% of the $M_{\text{gal}}$, fairly consistent with classical bulges. As a comparison, the $M_{\text{BH}}/M_{\text{NSC}}$ and $M_{\text{NSC}}/M_{\text{gal}}$ ratios are 16% and 0.26% in NGC 4395, respectively, which contains a relatively larger BH and yet comparable NSC mass. This may suggest that the BH and NSC in NGC 3319 are lying in the very early stage of growth, even earlier than the IMBH prototype object NGC 4395.

Another striking morphology feature of NGC 3319 is the strong bar with a length about 100″ (7 kpc). As a typical morphology feature of non-axisymmetric potential, the galactic bar can play an important role in the secular evolution of disk galaxies, which are capable of driving galactic-scale gas down to approximately pc scales (e.g., Shlosman et al. 1989; Friedli & Benz 1993; Wang et al. 2012). The resulting gas reservoir in the galaxy centers may serve to feed the BH, and thus bars have been suspected to be viable mechanisms to trigger AGN activity in spiral galaxies (e.g., Shlosman et al. 1990; Sakamoto et al. 1999; Jogee et al. 2005). However, many statistics show that the AGN activity is little affected by the presence of large-scale bars, on the basis of a larger sample and with selection...
effect accounted for (e.g., Hao et al. 2009; Lee et al. 2012; Goulding et al. 2017).

The hydrodynamical simulations do not only show that a bar is indeed able to transfer gas to the galactic center and form a central mass concentration, but also suggest that a seed SMBH could be created (e.g., Sellwood & Moore 1999; Fanali et al. 2015). Li et al. (2017) have revisited this model and argue that an NSC and perhaps a massive BH could form from the concentrated gas of low angular momentum during the bar-driven gas inflow, which will stall at a nuclear ring when the mass of the central object exceeds 1% of the disk mass. NGC 3319 may represent such a typical bar-driven growth scenario of SMBH seeds. According to Kormendy & Kennicutt (2004), a pseudobulge will form soon in this galaxy as a result of secular evolution. However, our analysis of SDSS spectrum suggests that the bar will experience a starburst in about ~130 Myr from now, but the major star formation has ceased as there are only weak Hα emission lines from H II regions. Therefore, the formation of the pseudobulge must go through with stellar dynamic processes rather than take part in the process of the formation of new stars. The coincidence of the M_{BH}/M_{NSC} and M_{NSC}/M_{gal} ratios to that of classical bulge suggests perhaps that NSC is the progenitor of the pseudobulge, although that physical process needs to be further understood.

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