Revisiting the Complex Kinematics of Ionized Gas at the Central Region of NGC 1068:
Evidence of an Additional Active Galactic Nucleus?

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Abstract

We present a spatially resolved analysis of ionized gas at the nuclear region of the nearby galaxy NGC 1068. While NGC 1068 has been known to have gas outflows driven by its active galactic nucleus (AGN), more complex kinematical signatures were recently reported, which were inconsistent with rotation or simple biconical outflows. To account for the nature of gas kinematics, we performed a spatially resolved kinematical study, finding a morphologically symmetric pair of approaching and receding gas blobs in the northeast region. The midpoint of the two blobs is located at a distance of 180 pc from the nucleus in the projected plane. The ionized gas at the midpoint shows zero velocity and high velocity dispersion, which are characteristics of an outflow-launching position, as the two sides of a bicone, i.e., approaching and receding outflows are superposed on the line of sight, leading to no velocity shift but high velocity dispersion. We investigate the potential scenario of an additional AGN based on a multiwavelength data set. While there are other possibilities, i.e., X-ray binary or supernova shock, the results from optical spectropolarimetry analysis are consistent with the presence of an additional AGN, which likely originates from a minor merger.

Unified Astronomy Thesaurus concepts: Active galactic nuclei (16); Spectroscopy (1558)

1. Introduction

NGC 1068, at a distance of 14.4 Mpc (Bland-Hawthorn et al. 1997), is a prototype Seyfert 2 galaxy with a well-studied active galactic nucleus (AGN). The first detection of the hidden broad-line region (BLR) was reported based on spectropolarimetric observations (e.g., Antonucci & Miller 1985). Since then, it has been widely accepted that the dichotomy of Seyfert 1 and Seyfert 2 galaxies is due to an orientation effect caused by a dusty molecular torus surrounding the BLR. The presence of molecular tori has been observationally confirmed by high spatial resolution observations (e.g., García-Burillo et al. 2016; Imanishi et al. 2016, 2018; Combes et al. 2019). The mass of the central black hole was reliably measured as $M_{\text{BH}} = 0.8 \pm 1.7 \times 10^7 M_{\odot}$ based on spatially resolved maser kinematics (Greenhill et al. 1996; Huré 2002; Lodato & Bertin 2003; Impellizzeri et al. 2019), while the bolometric luminosity was determined as $L_{\text{bol}} = 2.4 \pm 4.7 \times 10^{11}$ erg s$^{-1}$ in various ways using multiwavelength data (Gravity Collaboration et al. 2020 and references therein). The corresponding Eddington ratio ranges from 0.19 to 4.7, indicating a high accretion rate.

One intriguing feature of NGC 1068 is that ionized gas kinematics shows complexity in the central region (i.e., $<500$ pc) as reported by Walker (1968) and subsequent studies. Using various spectroscopic data, including HST observations, detailed analysis has been conducted to constrain the origin of the gas kinematics. Biconical gas outflows have mainly been interpreted as being driven by the central AGN and manifest as an approaching gas blob in the northeast (NE) region and a receding gas blob in the southwest (SW) region from the nucleus (Cecil et al. 1990; Arribas et al. 1996; Axon et al. 1998; Crenshaw & Kraemer 2000; Cecil et al. 2002; Das et al. 2006; Gerssen et al. 2006).

In contrast, there were reports of an additional receding (redshifted) gas blob, which was detected at $2^\alpha 5.5−4^\alpha 5$ (i.e., $180−320$ pc) NE of the nucleus (e.g., Axon et al. 1998; Cecil et al. 2002). Because this gas blob disagrees with the trend of the well-known biconical outflows (i.e., approaching in NE), more complex mechanisms are likely to be responsible for the change in the velocity sign in the NE region. While the receding gas blob in the NE region was claimed to be the result of (1) the lateral expansion of radio jets (Axon et al. 1998; Cecil et al. 2002), or (2) escaped radiation through a patchy dust torus or scattered radiation (Das et al. 2006), the origin of the complex gas kinematics is yet to be clearly understood.

To constrain the origin of the complex gas kinematics at the nuclear region, we performed a spatially resolved spectroscopic analysis by utilizing the VLT/MUSE data. We describe the data and analysis in Section 2. The main results and discussion are followed in Sections 3 and 4. Conclusions are presented in Section 5. We adopt a cosmology with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.7$, and $\Omega_{\Lambda} = 0.3$.

2. Data and Analysis

2.1. Data

NGC 1068 was observed with the VLT/MUSE as a part of the MAGNUM survey (094.B-0321(A) PI: A. Marconi), which covered a $1^\prime \times 1^\prime$ (i.e., $4.3$ kpc $\times 4.3$ kpc) field of view (FOV). Mingozzi et al. (2019) analyzed the MUSE data to investigate the properties of outflowing gas (e.g., density and ionization parameter), while the kinematics of ionized gas, particularly at the central 1 kpc scale, was not presented in their work. In this paper, we focus on the central region and present the detailed gas kinematics. The observation consists of 12 exposures, the exposure time of which was 500 s for four exposures (observed
on 2014 October 6) and 100 s for eight exposures (observed on 2014 December 1). For this work, we only utilized the eight 100 s exposures since [O III] and Hα are saturated at a few central pixels in the 500 s exposures. The data were retrieved from the ESO archive and reduced using the standard reduction pipeline of the VLT instruments, ESOREFLEX (Freudling et al. 2013). The seeing of the individual exposures ranged from 0″81 to 0″98, corresponding to ∼58–71 pc at the distance of NGC 1068.

2.2. Analysis

We performed a spectral fitting analysis by focusing on the central 14″×14″ (or 1 kpc × 1 kpc) region. While the MUSE data covered several kiloparsec scales as described in Section 2.1, the complex gas kinematics was reported within the central ~5″ (or ~350 pc) region, where ionized gas showed high velocity as well as high velocity dispersion (i.e., $V_{[O\,III]} > 1000 \text{ km s}^{-1}$ and $\sigma_{[O\,III]} > 1000 \text{ km s}^{-1}$), e.g., Cecil et al. 2002; Das et al. 2006). Outside the central ~5″ region, gas velocity and velocity dispersion are typically less than 100 km s$^{-1}$, which are comparable to those of the stellar component of NGC 1068 (e.g., Emsellem et al. 2006). We checked the whole FOV of the MUSE data (1′×1′) and confirmed that gas kinematics in large scales generally follows the rotation of the galaxy without showing a strong outflow signature (i.e., high velocity). We analyzed optical emission lines, i.e., [O III]5007, Hσ, and [Fe VII]6087, to trace gas kinematics and stellar absorption lines to investigate stellar kinematics, as extensively performed in our previous works (e.g., Bae & Woo 2014; Karouzos et al. 2016a, 2016b; Woo et al. 2016, 2017; Bae et al. 2017; Kang & Woo 2018; Luo et al. 2019; Shin et al. 2019).

First, we fitted and subtracted the stellar continuum on a spectral range of 4800–6800 Å, using the pPXF code (Cappellari 2017) with 47 ages (from 60 Myr to 12.6 Gyr) and solar metallicity of the E-MILES template (Vazdekis et al. 2016). During the fitting, we masked every visible emission line as well as the Na I $\lambda\lambda5890,\lambda5896$ (Na D) doublet absorption line, which traces neutral gas outflows (e.g., Bae & Woo 2018), to avoid any possible contamination in the stellar continuum fitting. Then, we fitted emission lines (i.e., [O III] and Hα) with the MPFIT package (Markwardt 2009). To reproduce the observed emission lines, we adopted multiple Gaussians (up to three), whose amplitude-to-noise ratios are all larger than 3. The number of Gaussians was determined with the reduced chi-square of the fitting results. In the fitting, we tied the velocity and velocity dispersion for the (1) [O III] doublet and (2) Hσ and [N II] doublet, respectively. We also fixed the flux ratios of the [N II]$\lambda\lambda6548,6584$ and [O III]$\lambda\lambda4959,5007$ doublets as 3 and 2.98. Note that we used a consistent method as adopted by Shin et al. (2019), who analyzed the MUSE data of NGC 5728, except for the number of Gaussians (up to two in Shin et al. 2019).

From the best-fit model, we measured the flux, velocity, and velocity dispersion of each line from its whole line profile (i.e., flux-weighted line properties). Different from this work (and also Emsellem et al. 2006), each Gaussian component was investigated to understand individual gas components in several previous works of NGC 1068 (Cecil et al. 2002; Das et al. 2006; Gerssen et al. 2006). They divided the multiple Gaussian components based on line flux (i.e., highest to lowest; Das et al. 2006) or velocity (redshifted or blueshifted; Cecil et al. 2002). We tried to decompose the individual Gaussian components based on the same criteria (i.e., flux and velocity), while the decomposed components in 2D space show complex distributions, which is very difficult to interpret. Therefore, we measured the flux-weighted line properties to investigate the overall (or dominant) gas kinematics for the first step.

Second, we fitted the stellar continuum in the wavelength of 8400–8800 Å with the same method as used for 4800–6800 Å. Seyfert 2 galaxies generally show strong stellar absorption lines (i.e., Mg b, Fe5270, and Fe5335) in the optical wavelength (e.g., NGC 5728; Shin et al. 2019). This is also true for NGC 1068 except for its central ~2″×2″ region, where a strong nonstellar continuum is present, leading to unreliable fitting results of the stellar component (see Figures 6 and 7 of Gerssen et al. 2006). The MUSE data also showed a strong nonstellar continuum in the same central region. Therefore, we used another wavelength window, 8400–8800 Å, where the Ca II triplet is clearly detected, representing stellar kinematics. Even in this wavelength range, we also detected a nonstellar continuum and the features of emission lines, which are associated with e.g., [CI II] $\lambda\lambda5879,\lambda5896$, [Fe II] $\lambda\lambda6817$, and [N I] $\lambda\lambda6705,6716$. To avoid any contamination, we masked the wavelength window of 8555–8650 Å during the fitting and measured the stellar velocity and velocity dispersion. Overall, the stellar model fitting results are better in the Ca II triplet region than in the Mg–Fe region, indicating that the measured stellar kinematics from 8400 to 8800 Å could be more reliable than that from 4800 to 6800 Å.

3. Result

3.1. Stellar Component

In Figure 1, we present the maps of the flux, velocity, and velocity dispersion of the stellar component analyzed in the two wavelength ranges, (1) 4800–6800 Å and (2) 8400–8800 Å. Throughout the paper, we consider the highest flux point in the stellar continuum flux map as the center (0, 0) of NGC 1068. Without any astrometry correction, the center is offset by only ~0″1 (i.e., the half of the pixel size of the MUSE data) from the position of the peak of X-ray emission at the nucleus of NGC 1068 (R.A. = 2:42:40.71, decl. = −00:00:47.7; Young et al. 2001). We find that both of them commonly show a radially decreasing flux and a rotation pattern. We also find that the mean difference between the two velocity maps is 12.5 ± 20 km s$^{-1}$. This means that both velocity maps can be used as a reference for the systemic velocity.

In the case of the velocity dispersion maps, however, there is a significant discrepancy (the right panels of Figure 1). Using the 4800–6800 Å range, we find high velocity dispersion along the NE–SW direction. In contrast, when the 8400–8800 Å region was used, we detect a trend of $\sigma$ drop at the central circular region within a radius of ~1″. The central $\sigma$ drop was detected in a number of galaxies including NGC 1068 (Emsellem et al. 2004, 2006; Falcón-Barroso et al. 2006; Gerssen et al. 2006; Comerón et al. 2008; Kang et al. 2013) and its origin has been discussed as recent star formation at the nuclear region (e.g., Emsellem et al. 2001; Comerón et al. 2008; Storchi-Bergmann et al. 2012). We note that the reason for the high velocity dispersion along the NE–SW in the former one (the top-right panel of Figure 1) would be mainly due to the unreliable fitting result of the stellar continuum at the central
region as described in Section 2. As also presented in Gerssen et al. (2006), the stellar continuum fitting is unreliable at the region with high velocity dispersion.

### 3.2. Ionized Gas

We present the flux, velocity, and velocity dispersion maps of the two major optical emission lines, [O III] and Hα, as well as a coronal emission line, [Fe VII] in Figure 2. [O III] and Hα represent the ionized gas kinematics in the narrow line region (NLR), while [Fe VII] with a high ionization potential (99.1 eV) traces the coronal line region (CLR; e.g., Rodríguez-Ardila et al. 2006; Rodríguez-Ardila & Fonseca-Faria 2020). In the velocity maps, we use relative velocity (i.e., \( V_{\text{gas}} - V_{\text{a}} \)) at each spaxel in order to show the relative motion of gas with respect to the stellar component, for which velocity is measured from the stellar absorption line in the 8400–8800 Å range (bottom-middle panel of Figure 1). Because stellar velocity is much smaller than gas velocity, we find no significant change in the velocity map with/without subtracting stellar velocity.

First, the flux maps show an elongated distribution along the NE to SW direction, which represents an ionizing cone as discussed in the previous studies (e.g., Capetti et al. 1997).

Second, the velocity maps present a complex structure, with a wide range of line-of-sight velocity from \(-700 \text{ km s}^{-1}\) to \(+400 \text{ km s}^{-1}\). The much higher gas velocity than stellar velocity indicates that gas kinematics is mainly governed by the nongravitational effect, i.e., AGN-driven outflows, instead of the gravitational potential of the host galaxy. All velocity maps show a common kinematic structure by presenting four high-velocity gas blobs (i.e., \(|V| > 200 \text{ km s}^{-1}\)): one pair of blueshifted (B1) and redshifted (R1) blobs in the NE direction, and another pair of blueshifted (B2) and redshifted blobs (R2) in the SW direction as marked in the [O III] velocity map. Interestingly, R1 and B1 show morphologically similar tail-like structures, which are elongated roughly in the horizontal direction, implying that R1 and B1 are physically connected as a pair. The four gas blobs are also detected in the [Fe VII] velocity map, suggesting that the high-velocity gas blobs are driven by AGN rather than star formation because [Fe VII] has a high ionization potential, i.e., 99.1 eV. The positions of these gas blobs are slightly different depending on the tracer. For example, there is a \( \sim 0.2'' \) offset of the center of R1 between the [O III] and Hα velocity maps. The spatial offset is presumably due to the difference in ionizing sources. While Hα (and also H/β) is ionized by AGN as well as star formation, [O III] and [Fe VII] are mainly ionized by AGN. In addition, the possible uncertainty of the [Fe VII] velocity, which can be much larger than that of Hα and [O III] because of the lower flux of [Fe VII] (see Figure 2), can be partly responsible for the offset. Because the exact position of these gas blobs is not the main interest for our analysis, we determined the location of gas blobs using the [O III] velocity map.

The high-velocity gas blobs are spatially resolved in the HST narrowband image (Capetti et al. 1997). For example, the gas
blob B1 is resolved into a couple of smaller blobs. Without velocity information, however, it is difficult to constrain how the substructure of B1 detected in the narrowband image is related to the outflows. Previous studies of gas kinematics based on the HST/STIS data showed consistent features compared to those presented in this work (Cecil et al. 2002; Das et al. 2006). For example, a cloud located at the center of B1 also showed negative velocities, $\sim 600$ km s$^{-1}$ (see Figure 3 of Cecil et al. 2002).

The velocity structure presented in this work is very different compared to the biconical outflows in Seyfert galaxies, which typically show a pair of blueshifted and redshifted gas blobs (e.g., NGC 5728; Durré & Mould 2019; Shin et al. 2019). While previous studies treated B1 and R2 as approaching and receding gas outflows, respectively, driven by the AGN at the nucleus of NGC 1068 (e.g., Das et al. 2006), there are apparently additional gas blobs (R1 and B2) whose gas kinematics is inconsistent with a single biconical outflow.

To better understand the intriguing kinematical structure, we present one-dimensional velocity distributions by locating two pseudo-slits in the $\text{[O III]}$ velocity map: (1) one through the nucleus of NGC 1068 and R1 (slit 1, solid line, PA $= 44^\circ$) and (2) another along the orientation of the radio jet (slit 2, dotted line, PA $= 30^\circ$; Wilson & Ulvestad 1983). As shown in Figure 3, the position angle of Slit 1 is tilted $\sim 14^\circ$ from the orientation of a radio jet, which has PA $= 30^\circ$ (Wilson & Ulvestad 1983). We find a dramatic variation of gas velocity along Slit 1 (i.e., B1 to R1), which indicates the change of outflow direction at the radius of $\sim 190$ pc (and also $\sim 200$ pc). The change of gas velocity along Slit 2 (i.e., jet...
direction through R2) is slightly less but clearly shows a change in velocity sign. Moreover, we detect a significant flux bump around R1 (middle right panel of Figure 3). While it is difficult to quantify the additional flux, the [O III] flux around R1 is somewhat increased (\(\sim 0.1 - 0.2\) dex), particularly compared to the flux distribution of Slit 2. In contrast, there is no significant flux excess in R2. Based on these results, we interpret that the kinematical signature of R1 is not related to the radio jet but caused by the flux contribution from another source at X1.

Third, the velocity dispersion maps also show a complex kinematical structure. Within 5\(''\) (i.e., \(\sim 350\) pc) from the nucleus, the velocity dispersion (\(>300\) km s\(^{-1}\)) is significantly higher than stellar velocity dispersion (\(\sim 150\) km s\(^{-1}\)), indicating the strong nongravitational kinematics of ionized gas. We find that the velocity dispersion is even higher (up to 800 km s\(^{-1}\)) at the midpoint between B1 and R1 (marked as X1 in Figure 2). In contrast, the gas velocity is almost zero at X1. Because high velocity dispersion and zero velocity are typically detected at the launching point of gas outflows in nearby AGNs (e.g., NGC 5728, Durré & Mould 2019; Shin et al. 2019), these features suggest that the R1 and B1 gas blobs represent outflows, which are launched at the position of X1.

3.3. Emission-line Flux Ratios

In order to understand the ionization mechanism, we investigate emission-line flux ratios and identify the major ionizing source (i.e., AGN, star-forming, low-ionization nuclear emission-line region (LINER), or composite region), using the Baldwin–Phillips–Terlevich (BPT) diagrams with three diagnostics ([N II], [S II], and [O I]; e.g., Baldwin et al. 1981; Kewley et al. 2006). We confirm that AGNs and LINERs are the major ionizing sources within 5\(''\) (or \(\sim 350\) pc), while star formation ionizes gas in the outskirts of the FOV as...
previously reported (see Figure 4; D’Agostino et al. 2019; Mingozzi et al. 2019). The high-velocity gas blobs are mainly ionized by AGNs, suggesting that outflows in these blobs are likely driven by AGNs.

In Figure 5, we present the [O III]/Hβ ratio map to trace the ionization parameter. As expected from the BPT maps, the ratio is high (>5) in the ionized region, where AGNs are the main ionizing source. However, the [O III]/Hβ ratio ranges from ~5 to ~10, and the R1 and B1 blobs show relatively high [O III]/Hβ ratios. We find two interesting features in the ratio map. First, the highest ratio is detected in the gas blob B1 (i.e., ~1″ NE from position X), instead of the nucleus. By reporting this feature, previous studies discussed that shocks from the interaction between the ratio jet and interstellar medium (ISM) play as an additional ionizing source in elevating the [O III]/Hβ ratio in the NE region (e.g., Kraemer et al. 1998; Kraemer & Crenshaw 2000; Cecil et al. 2002). Second, the region with a high [O III]/Hβ ratio (i.e. >5) has a biconical shape centered at X1 (see red dashed lines in Figure 5), suggesting that B1 and R1 are a pair of gas blobs, which are launched at X1 as discussed in the previous section.

4. Discussion

4.1. The Origin of Intriguing Kinematics

Based on the spatially resolved analysis of the central region of NGC 1068, we present the complex kinematical signature of ionized gas, which is inconsistent with either the host galaxy gravitational potential or a simple biconical outflow scenario. We find a pair of two distinct gas blobs (i.e., R1 and B1), which show a kinematically similar morphology in the gas velocity map and share a consistent radial velocity structure with a similar increasing and decreasing trend. Based on the kinemorphological symmetry, we interpret that the two blobs represent a pair of receding and approaching gas blobs, which are centered at a launching position (X1) at a projected distance of 180 pc from the galaxy center.

While the gas blob B1 is interpreted to be the approaching side of outflows, which are launched from the nucleus (e.g., Cecil et al. 2002; Das et al. 2006), the gas blob R1 is moving in the opposite direction to B1. To explain the origin of R1, two scenarios have been suggested: (1) the lateral expansion of radio jets (e.g., Axon et al. 1998; Cecil et al. 2002) and (2) escaped radiation through a patch torus or scattered radiation (Das et al. 2006). These scenarios may explain the opposite orientation of R1 compared to B1 (see, e.g., Figure 6 of Cecil et al. 2002).

However, neither scenario is acceptable because such a change in velocity sign in outflows has not been reported in any other AGNs observed with gas outflows and radio jets. For example, in the cases of well-studied NGC 4151 and NGC 5728, the velocity structure of gas outflows is consistent with biconical outflows, manifesting as approaching gas in one side and receding gas in the other side, without changing the velocity sign in one direction (e.g., Das et al. 2005; Durré & Mould 2019; Shin et al. 2019).

Moreover, we find that the orientation from the nucleus (X) to the position X1 (i.e., PA = 44°) is tilted ~14° from the PA of the radio jet, which has PA = 30°. If the lateral expansion of radio jets and/or escaped radiation is the origin of R1, it is natural to expect a similar gas blob, which is laterally expanded from the jet and located in the opposite direction (i.e., PA = 16°; see the slit position in Figure 3). In other words,
a symmetric gas blob would be located on the other side of the jet. In contrast, we find no structure in that position (at ΔR, Δfi = ~0", Δdecl. = ~3") where it is possible that the lack of ionized gas in that location may explain why the lateral expansion or escaped radiation is morphologically asymmetric (top-right panel of Figure 3). In addition, it was pointed out that radio jets are not energetic enough to drive strong gas outflows (Das et al. 2006). Therefore, the two aforementioned scenarios cannot fully explain the observed flux and velocity structures around R1, implying that the AGN at the nucleus of NGC 1068 may not be responsible for the kinematics of the gas blob R1.

We propose a new scenario where there is an additional (second) mass-accreting black hole around the position X1, and the outflows driven by the second AGN at X1 are manifested by a pair of receding (R1) and approaching (B1) gas blobs. We present several supporting evidence. First, as presented in Section 3.2, ionized gas at X1 shows zero velocity and high velocity dispersion, which are typical observational characteristics of an outflow-launching point in nearby Seyfert galaxies (e.g., NGC 5728; Durré & Mould 2019; Shin et al. 2019). This trend is due to the fact that the two sides (i.e., receding and approaching) of the gas outflows are superposed along the line of sight at their launching point because of the beam smearing effect, hence, the cancellation between positive and negative velocities leads to net zero velocity, while the broad velocity distribution results in high velocity dispersion (e.g., Durré & Mould 2019; Shin et al. 2019). Therefore, our scenario of a second AGN can naturally explain the gas kinematics at X1. Second, the morphological symmetry (i.e., the elongated tail-like structures) between R1 and B1 in the velocity map suggests that they are physically related, sharing the same origin (i.e., the second AGN). Third, we detect the radial velocity pattern of acceleration followed by deceleration for both of the gas blobs R1 and B1, which are centered at the potential launching position X1 (see Figure 3). This increasing and decreasing velocity pattern is a signature of gas outflows detected in a number of nearby AGNs (Crenshaw & Kraemer 2000; Crenshaw et al. 2000; Müller-Sánchez et al. 2011; Durré & Mould 2019). While the radial velocity pattern, as well as the relatively high gas velocity in NGC 1068, was already noticed in previous studies (Crenshaw & Kraemer 2000; Müller-Sánchez et al. 2011), gas outflows are assumed to be launched from the nucleus. Fourth, we find a biconical shape centered at X1 in the [O III]/Hβ ratio map, which is presumably due to an ionizing source at X1 (i.e., the second AGN). Note that the approaching gas blob B1 was considered to be driven by the first AGN at the nucleus in the previous studies (e.g., Cecil et al. 2002; Das et al. 2006; Gerssen et al. 2006). However, the gas blob B1 is more extended than R1, covering the two slit positions shown in Figure 3, and it is likely that B1 is the combination of the approaching gas blobs, which are launched from the nucleus and position X1, respectively (see the schematic view of two pairs of biconical outflows in Figure 6).

We investigate whether the kinematics of gas blobs R1 and B1 can be explained by a rotating disk, which is centered at X1. As shown in the lower panel of Figure 3, the peak velocity of B1 and R1 reaches ~500 km s⁻¹ at the projected distance of only ~50 pc from X1. To produce a rotational velocity of 500 km s⁻¹ at 50 pc, the required enclosed mass needs to be a minimum of 10^{10.5} M☉, when the disk is assumed to be edge on. For the case of NGC 1068, however, the enclosed mass within the central 50 pc is only 10^{8.2} M☉, as estimated based on the stellar rotational velocity (i.e., ~30 km s⁻¹ at 50 pc from the nucleus) and the inclination (i.e., 40°, Bland-Hawthorn et al. 1997). Because the expected mass of the gas disk at X1 is a factor of ~200 higher than that based on stellar kinematics, a rotating gas disk is not likely responsible for the kinematics of gas blobs B1 and R1. Previous studies of nearby AGNs, including NGC 1068, pointed out the same conclusion that such high velocity (>300 km s⁻¹) of ionized gas is due to gas outflows, not galactic disk rotation (e.g., Müller-Sánchez et al. 2011; Durré & Mould 2019).

Alternatively, supernova (SN) may be the origin of R1 as there was a report of high-velocity molecular gas outflows (V ≥ 500 km s⁻¹) driven by an SN in NGC 6240 (Treister et al. 2020). However, an SN is not likely responsible for R1, because of the following two reasons. First, as shown in Figure 4, the major ionizing source for R1 is AGNs (see also D’Agostino et al. 2019; Mingozzi et al. 2019). While D’Agostino et al. (2019) found significant shock contribution in the central region (~0.5 kpc × 1 kpc), it was interpreted to be due to the gas outflows launched from the first AGN of NGC 1068, but not due to other mechanisms (i.e., SN). Second, an X-ray study by Ogle et al. (2003) showed that a region around X (i.e., 3° NE of the nucleus) is mainly photoionized rather than collisionally ionized, implying that AGNs (not SN) are the major ionizing source of the region. In fact, our BPT
analysis clearly showed that the photoionization of R1 is dominated by AGNs (see Figures 4 and 5). Note that we cannot rule out the SN origin of R1 if the SN-driven photoionization is relatively weak and undetectable as the BPT map requires. In this case, it is not clear how the SN provides a strong impact on the gas kinematics.

One may expect a light excess around X1 in the flux map, if there is indeed a mass-accreting black hole. While we find no strong evidence, we detect an excess of [O iii] flux around X1 in the flux map of ionized gas (see Figure 3). In contrast, there is no signature of dynamical disturbance in the stellar and kinematical maps, which may suggest that the galaxy–galaxy mass ratio is very large and the contribution of the merged component is negligible and not detected in the flux-weighted stellar absorption lines. The possibility of minor mergers in NGC 1068 has been discussed based on the detections of (1) ultra-diffuse objects around NGC 1068 (Tanaka et al. 2017), (2) an off-centered circumnuclear disk (CND; García-Burillo et al. 2014), and (3) the non-Keplerian motion of molecular gas in the molecular torus (e.g., Imanishi et al. 2018). We note that García-Burillo et al. (2014) also discussed the presence of another AGN in the SW of the nucleus (ΔR.A. = −1°.50, Δdecl. = −1°.00) to explain the off-centered CND even though it is yet to be observationally confirmed.

Recently, Wang et al. (2020) claimed a close binary supermassive black hole (SMBH) with a separation of ∼0.1 pc, in order to account for a counterrotating disk at the nucleus of NGC 1068. If the subparsec-scale binary, as well as our proposed second AGN, is present, it means that NGC 1068 contains three SMBHs. While the observational evidence for triple SMBHs are scarce, a few triple SMBHs have been recently detected (e.g., NGC 6240, Kollatschny et al. 2020; and SDSS J0849+1114, Liu et al. 2019; Peiße et al. 2019). According to the cosmological simulation by Kelley et al. (2017), triple SMBHs are expected to be up to 30% among binary SMBHs, suggesting that the presence of a triple SMBH in NGC 1068 is feasible although confirmation is beyond the scope of this work.

4.2. Counterpart in Multiwavelength Data

To investigate whether the second AGN scenario is consistent with other observational signatures, we use X-ray and radio data and search for evidence of multiple cores at the central region. Starting with X-ray data, we check the Chandra high-resolution camera (HRC) data of NGC 1068 (ObsID: 12705; PI: Fabbiano), which were previously presented by Wang et al. (2012). As shown in the top-right panel of Figure 1 of Wang et al. (2012), the Chandra image with PSF deconvolution resolves another putative X-ray point source 3°/6 NE of the nucleus (ΔR.A. = +2°.00, Δdecl. = +2°.75). The detection of the point source is significant at the >7σ level when we take into account the Poisson noise of the adjacent pixels. The position of the X-ray point source is close to the center of the pair of gas blobs R1 and B1 (i.e., X1 position), albeit with an offset of ∼0°.9 to the NE of X1, and it is likely to represent the second AGN around X1. The spatial offset can be explained by various effects (i.e., dust obscuration and ISM impact), which can cause the positional shift of the kinematic center of the gas outflows (i.e., X1) from the position of an X-ray point source, where an AGN is located (see, e.g., Durré & Mould 2018). For example, a ∼0°.7 separation was found between the kinematic center of gas outflows and the position of the central X-ray point source in NGC 5728 (Durré & Mould 2019; see also Shin et al. 2019).

To investigate the possibility of the X-ray point source as a potential AGN, we measure the X-ray luminosity in 2–10 keV by converting the X-ray photon counts (133) at the pixel of the X-ray point-source position, using the PSF deconvolved Chandra HRC image. For this practice, we calculate a conversion factor from WEBPIMMS\(^5\) using the effective area curve of Chandra Cycle 12, a power-law index (Γ = 1.8), and a Galactic column density (N\(_{\text{H}}\) = 2.99 × 10\(^{20}\) cm\(^{-2}\), Murphy et al. 1996). As a result, we obtain the 2–10 keV X-ray luminosity as ∼8.7 ± 0.8 × 10\(^{38}\) erg s\(^{-1}\). Note that the uncertainty is from Poisson statistics. The X-ray luminosity is not sufficiently high to confirm the presence of an additional AGN because X-ray binaries can be the origin of the X-ray emission. Note that the Eddington luminosity of a 10\(^{5}\) M\(_{\odot}\) stellar black hole is ∼10\(^{39}\) erg s\(^{-1}\), while the luminosity of high-mass X-ray binaries is typically less than 10\(^{39}–10^{40}\) erg s\(^{-1}\) (e.g., Grimm et al. 2003; Fabbiano 2006; Mineo et al. 2012).

We investigate the possibility that the luminosity of the X-ray point source is underestimated as the potential second AGN is likely to be type 2 without presenting broad emission lines in the optical spectrum. In this case, we do not directly measure the intrinsic luminosity because of the obscuration by a dust torus. It has been known for the first AGN in NGC 1068 that the transmitted X-ray emission from the central source is completely obscured by a dust torus as the column density of this Compton-thick source is \(N_{\text{H}}\) ∼10\(^{25}\) cm\(^{-2}\). Thus, it is difficult to measure the intrinsic X-ray luminosity as we only observe the X-ray emission reflected by the inner wall of the dust torus and ionized gas (Colbert et al. 2002; Ogle et al. 2003; Matt et al. 2004; Bauer et al. 2014; but see also Marinucci et al. 2016). To determine the intrinsic X-ray luminosity, for example, Colbert et al. (2002) used the [O iii] luminosity as a proxy for the bolometric luminosity of the central AGN, estimating the intrinsic X-ray luminosity of ∼3.2 × 10\(^{43}\) erg s\(^{-1}\), which is a factor of 250 higher than the reflected X-ray luminosity. More reliably, Bauer et al. (2015) performed X-ray spectral analysis, reporting the intrinsic X-ray luminosity of the central AGN as 2.2 × 10\(^{43}\) erg s\(^{-1}\) (see Marinucci et al. 2016).

In the case of the potential second AGN, we cannot use the same correction factor obtained for the first AGN because the second AGN is not likely a Compton-thick source. Instead, a proper spectral analysis is required to determine the intrinsic X-ray luminosity. Note that the AGN X-ray spectrum is complex as it is composed of various components, including soft X-ray access and a power-law component. Due to the lack of spectral information on the X-ray source around X1, we estimate the intrinsic X-ray luminosity from the observed X-ray luminosity by assuming a typical column density for type 2 AGNs and calculate the correction factor with WEBPIMMS.\(^6\) We obtain a range of the obscuration correction factor from 1.06 and 7.14, depending on the column density \(N_{\text{H}}\) = 10\(^{22}\) to \(N_{\text{H}}\) = 10\(^{24}\). As an example, if we multiply the correction factor of 1.56, corresponding to \(N_{\text{H}}\) = 10\(^{23}\), to the observed X-ray luminosity of ∼8.7 × 10\(^{38}\) erg s\(^{-1}\), the intrinsic X-ray luminosity is 1.3 × 10\(^{39}\) erg s\(^{-1}\). While we cannot measure the exact correction factor for the X-ray source due to the lack of X-ray

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\(^5\) http://cxc.harvard.edu/toolkit/pimms.jsp

\(^6\) https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3pimms/w3pimms.pl
spectral information, it is likely that the intrinsic X-ray luminosity is not sufficiently high to rule out a high-mass X-ray binary as an origin.

In addition, we analyze Advanced CCD Imaging Spectrometer (ACIS) data (ObsID = 370, 0.4 s frame, exposure time = 11.5 ks), which were presented by Young et al. (2001), in order to check whether the X-ray spectrum of the X-ray point source shows a power-law continuum, as a power-law continuum is another observational signature of AGNs. Note that we do not investigate deeper data (ObsID = 344, 3.2 s frame, exposure time = 47.4 ks), which were heavily affected by pile-up at around X1 (and also the nucleus) because of the high count rate (see Young et al. 2001). We extract the ACIS spectrum from the position of the X-ray point source as detected in the Chandra HRC image with a radius of 0.5″. Then, we fit the spectrum with various combinations of (1) a single-temperature plasma model (MEKAL), (2) bremsstrahlung, (3) power law, and (4) a thermal plasma component (APEC). All of the models include absorption by the Galactic column density ($N_H(Gal) = 2.99 \times 10^{20} \text{ cm}^{-2}$; Murphy et al. 1996) as similarly done by Young et al. (2001). However, we find that the inclusion of a power law does not improve the fitting results compared to those without a power law.

To further investigate the origin of the X-ray point source, we measure the [O III] soft X-ray ratio, which is a tracer of ionization states (Bianchi et al. 2006). By investigating the ratio for several X-ray knots in the central region of NGC 1068, Wang et al. (2012) reported that a few of them originated from shocks. Using the same data set and method of Wang et al. (2012), we find the ratio of ~8.6 ± 0.86 at the pixel of the X-ray point-source position (i.e., within the extraction area of 0.7′′ × 0.7′′). This result indicates photoionization rather than shock. Note that the flux ratios, [O III]/Hδ and [N II]/Hα, [S II]/Hα, or [O I]/Hα, obtained around the X1 position are also consistent with AGN photoionization in the BPT diagrams. Thus, we conclude that X-ray emission is unlikely to originate from shocks unless [O III] flux is strongly dominated by the photoionization by the first AGN.

Second, we check the ALMA data of CO (3−2) (García-Burillo et al. 2014) and dense molecular gas (i.e., HCN (3−2) and HCO$^+$ (3−2)), presented by Imanishi et al. (2018), as well as the VLA radio data by used by Wilson & Ulvestad (1983) and Gallimore et al. (1996), while we do not find any strong signature (i.e., radio core) of the second AGN around X1. This can be explained with the low luminosity and/or the low mass of the host galaxy of the second AGN, as discussed in the previous section.

Overall, we find no clear evidence of a second AGN based on the multiwavelength data because the X-ray luminosity is relatively low and comparable to high-mass X-ray binaries. Nevertheless, we find no evidence to rule out the possibility of the second AGN.

4.3. Hidden Broad Emission Line

One of the characteristics of an AGN is the presence of broad emission lines (i.e., FWHM > 2000 km s$^{-1}$), which are emitted from the subparsec-scale BLR. For Seyfert 2 galaxies, the BLR is obscured by a dust torus, but it can be detected through spectropolarimetric observations. As described in Section 1, NGC 1068 is the first type 2 Seyfert galaxy whose hidden broad Balmer lines were detected (e.g., Antonucci & Miller 1985). Since then, a number of spectropolarimetric results have been presented for NGC 1068. Among them, spatially resolved spectropolarimetric studies (Inglis et al. 1995; see also Miller et al. 1991) found the interesting result that the line width of the hidden broad Balmer lines detected in the NE (e.g., ~3250 ± 400 km s$^{-1}$ at 5″, or 360 pc NE) of the nucleus is significantly smaller than that detected at the nucleus (~4400 ± 300 km s$^{-1}$). Inglis et al. (1995) presented the line-width measurements of the hidden broad Hα line, which were detected at multiple points from the nucleus to the NE direction (i.e., 2″5 and 7″5 offset, corresponding to 180, 360, and 540 pc distance from the nucleus) and shows consistency (~3000 km s$^{-1}$) within 1σ (see the upper panel of Figure 7). This result may suggest that the hidden broad Hα detected in the NE has a different origin from that at the nucleus. One possible explanation is that there is an additional AGN in between 2″5 and 7″5 (or 180−540 pc) NE of the nucleus, whose hidden broad lines are intrinsically narrower than those of the first AGN at the center because of the smaller black hole mass of the second AGN.

As shown in the lower panel of Figure 7, the line flux of the hidden broad Hα line rather increases 360 pc NE of the nucleus, which is in disagreement with the trend of radially decreasing flux if it originated from the nucleus. This trend is consistent with the scenario of a second AGN at a distance of 360 ± 90 pc NE from the nucleus. Note that the kinematic center of R1 and B1 is X1, which is positioned 180 pc from the nucleus; however, the true location of an AGN can be somewhat offset from the kinematical center as discussed in Section 4.2. It is worth noting that imaging polarimetric observations have detected a highly polarized knot 4″7 NE of the nucleus (Miller et al. 1991; Scarrott et al. 1991; Simpson et al. 2002). It could be also associated with the second AGN while it is 2″ offset from X1.

In previous works, the origin of the broad Balmer emissions and high polarized intensity in the NE region was interpreted as the scattered light from the nucleus (e.g., Miller et al. 1991; Inglis et al. 1995) and molecular gas, which prevents the expansion of the radio jets (Simpson et al. 2002), respectively. However, these scenarios cannot clearly explain the difference in the line widths in the NE region as well as the bump in the flux distribution at 360 pc. In contrast, the scenario with the second AGN positioned around X1 may provide a better explanation.

4.4. Mass Outflow Rate and Energetics

We discuss whether the energetics of the potential second AGN is eligible to drive gas outflows manifested by gas blobs B1 and R1 by investigating the mass outflow rate and kinetic energy output. We use two different methods, namely, geometric and luminosity approaches (see e.g., Revalski et al. 2018).

4.4.1. Geometric Approach

For the geometric approach, the mass outflow rate and energy budget can be calculated as follows (see, e.g., the equation 1 of Müller-Sánchez et al. 2011),

$$M_{out} = 2 m_p N_e v_{max} A f, \quad (1)$$

$$E_{out} = 1/2 M_{out} (v_{max}^2 + \sigma^2). \quad (2)$$

This approach is based on a geometric assumption by determining five parameters: (1) the electron density, $N_e$, (2) the deprojected
maximum outflow velocity, \( v_{\text{max}} \), (3) the lateral surface area of outflows at the maximum velocity position, \( A \), (4) the averaged velocity dispersion in gas outflows, \( \sigma \), and (5) the filling factor, \( f \). Because we interpret B1 as superposed outflows, respectively launched from X and X1, we only use R1 to calculate outflow parameters. First, we estimate the electron density based on the [S II] \( \lambda \lambda 6717/\lambda 6731 \) ratio, which is measured from a flux-weighted spectrum extracted within a 1″ radius from the maximum velocity position in R1. By assuming the electron temperature to be 10,000 K, we obtained an electron density of 907 cm\(^{-3}\), which is consistent within ~10% with the previously reported value (Mingozi et al. 2019; i.e., ~800 cm\(^{-3}\)). Second, we adopt the (projected) maximum velocity of [O III] in R1 (i.e., 291 km s\(^{-1}\)) as the lower limit from the velocity map (see Figures 2 and 3) because the inclination of the outflows is unknown. Third, we estimate the lateral surface by determining the size of the major axis of R1. If outflows have a biconical shape, the lateral surface would be round, which is shown as an ellipse in the plane of the sky. Thus, the size of the major axis can be used to calculate the area of a circle. Based on this idea, we determine the size of the major axis to be 2″ (i.e., 142 pc) by drawing a line through the maximum velocity position in R1, which is perpendicular to the gas outflow direction (i.e., Slit 1; see Figure 3). To account for the hollow shape of outflows (e.g., Müller-Sánchez et al. 2011; Bae & Woo 2016; Shin et al. 2019), we adopt the hollow cone geometry of the first gas outflows, which were constrained as outer angle = 27° and inner angle = 14°, based on biconical gas outflow modeling by Müller-Sánchez et al. (2011). Using these estimates, we calculate the lateral surface area as \( 1.3 \times 10^7 \) pc\(^2\). Fourth, the average velocity dispersion in R1 is measured as 485 km s\(^{-1}\) using the same spectrum used for electron density estimation. Finally, we adopt the filling factor of 0.11 from Storchi-Bergmann et al. (2010), who calculated the filling factor for gas outflows in NGC 4151. Because we adopt the projected maximum velocity, these parameters provide the lower limit of the mass outflow rate and energy outflow rate as \( M_{\text{out}} = 18.1 \, M_\odot \, \text{yr}^{-1} \) and \( E_{\text{out}} = 1.9 \times 10^{42} \, \text{erg s}^{-1} \), respectively.

For a consistency check, we calculate the energetics of the gas outflows (R2) driven by the first AGN. Applying the same method to R2, we measure the averaged electron density in R2 (479 cm\(^{-3}\)), the maximum velocity (321 km s\(^{-1}\)), the lateral surface area (0.8 × 10\(^3\) pc\(^2\)), and the averaged velocity dispersion in R2 (544 km s\(^{-1}\)). By adopting the same filling factor of 0.11, we obtain the lower limit of the mass outflow rate as 6.5 \( M_\odot \) yr\(^{-1}\) and the energy outflow rate as 8.2 \( \times 10^{41} \) erg s\(^{-1}\). If we adopt the inclination of the first gas outflows (i.e., 9°) presented by Müller-Sánchez et al. (2011), the deprojected (intrinsic) maximum velocity becomes 2057 km s\(^{-1}\), which is consistent within 10% with that constrained by Müller-Sánchez et al. (2011). We find that the mass outflow rates and kinetic energy are \( M_{\text{out}} = 38.8 \, M_\odot \, \text{yr}^{-1} \) and \( E_{\text{out}} = 4.8 \times 10^{43} \, \text{erg s}^{-1} \), respectively, which are consistent within an order of magnitude with those reported by Müller-Sánchez et al. (2011).

### 4.4.2. Luminosity Approach

The luminosity approach calculates mass outflow rate and energy budget as follows,

\[
M_{\text{out}} = 3M_{\text{gas}} \frac{v_{\text{out}}}{R_{\text{out}}} 
\]

\[
E_{\text{out}} = \frac{1}{2} M_{\text{gas}} v_{\text{out}}^2, 
\]

where \( M_{\text{gas}} \) is the ionized gas mass, \( v_{\text{out}} \) is the averaged outflow velocity (i.e., \( v_{\text{out}} = \sqrt{v_{\text{gas}}^2 + \sigma^2} \)) within the outflows, and \( R_{\text{out}} \) is the outflow size (e.g., Karouzos et al. 2016b; Bae et al. 2017; Kang & Woo 2018). First, the ionized gas mass is converted from the [O III] luminosity with an estimated electron density using the equation \( M_{\text{gas}} = 0.4 \times 10^8 M_\odot \times (L_{\text{[O III]}}/100 \text{ cm}^{-3}/n_e) \) (see, e.g., Carniani et al. 2015; Karouzos et al. 2016b). In previous works by our group (e.g., Karouzos et al. 2016b; Bae et al. 2017), the ionized gas mass was estimated using the integrated [O III] luminosity within the outflow size. If NGC 1068 hosts an additional AGN along with its corresponding gas outflows, it is not trivial to measure the [O III] emission solely due to the photoionization by the second AGN. For simplicity, we constrain the upper limit of the ionized gas mass by combining [O III] flux around X1. We calculate twice the integrated [O III] luminosity in R1 (4.6 \times 10^{40} \text{ erg s}^{-1}) within a 1″ radius as the [O III] luminosity and calculate the ionized gas mass to be \( M_{\text{gas}} = 2 \times 10^6 M_\odot \), using the average electron density in this region (907 cm\(^{-3}\)). Note that assuming a bicone, we multiply a factor of 2 to the [O III] luminosity of R1. Because a large fraction of the warm gas is photoionized by the first AGN, the derived gas mass should be considered as an upper limit. While the [O III] map in Figure 2 shows a dominance of photoionization by the first AGN even at the R1 area, we detect additional flux at the X1 and R1 areas as shown in Figure 3, which is presumably due to the photoionization by the second AGN. While it is difficult to estimate the fraction of the ionized gas flux due to the second AGN with respect to the total [O III] flux in R1 area, the fraction should not be negligible because we clearly detect distinct kinematical signatures in the velocity and velocity dispersion maps based on

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**Figure 7.** One-dimensional distribution of the FWHM (upper) and line flux (lower) of the hidden broad component of Hα. A dotted line denotes the position of X1. All measurements are adopted from Inglis et al. (1995).
the flux-weight [O III] line profile. If we assume the [O III] flux due to the second AGN is \(\sim 1\% - 10\%\), the total gas mass should be corrected accordingly. Second, the average outflow velocity is calculated using the average velocity (232 km s\(^{-1}\)) and velocity dispersion (485 km s\(^{-1}\)) in R1. Third, we determine the outflow size as 140 pc (or \(\sim 2''\)), which is estimated at the position where the [O III] velocity approaches 100 km s\(^{-1}\) (see \(\sim 330\) pc in the middle panel of Figure 3). Note that the size of outflows is uncertain, and we simply use this value as our best approximation. As a result, we obtain the upper limit of the gas mass and energy outflow rate as \(M_{\text{out}} = 0.24 M_{\odot} \text{ yr}^{-1}\) and \(E_{\text{out}} = 2.2 \times 10^{40} \text{ erg s}^{-1}\). The actual gas mass and energy outflow rate should be corrected by the fraction of the [O III] flux due to the second AGN over the total [O III] flux.

4.4.3. Comparison of Outflow Energetics with Bolometric Luminosity

Based on the two aforementioned methods, we estimate the mass outflow rate and energy outflow rate. However, there is a large discrepancy between them by \(\sim 2\) orders of magnitude, indicating the systematic uncertainties of the outflow energetics. Harrison et al. (2018) pointed out that there are large differences in the mass outflow rate and energy outflow rate among various studies due to the different analysis methods and inhomogeneous definitions of the outflow size and velocity. Revalski et al. (2018) also discussed the huge difference between the outflow rates measured from the two methods and recommended using the luminosity approach because it better traces the physical parameters of gas outflows (i.e., ionized gas mass). While the derived mass outflow rate and energy outflow rate are within the range of the reported values in the literature (e.g., Greene et al. 2011; Harrison et al. 2014; Karouzos et al. 2016b; Bae et al. 2017; Rakshit & Woo 2018), we emphasize that there are large systematic uncertainties in determining outflow energetics.

Nevertheless, we compare the derived outflow energetics with AGN bolometric luminosity to investigate the kinetic coupling efficiency (i.e., \(E_{\text{out}}/L_{\text{bol}}\)). To estimate the bolometric luminosity of the second AGN, we utilize two different indicators, X-ray luminosity and [O III] luminosity. If we use the luminosity of the X-ray source around X1 with an obscuration correction factor of 1.56 for \(N_H = 10^{23}\) cm\(^{-2}\) and a bolometric correction factor of 10.85, we obtain the bolometric luminosity of the second AGN as \(L_{\text{bol}} = 1.5 \times 10^{40} \text{ erg s}^{-1}\). Here the bolometric correction factor is calculated based on Equation 2 of Duras et al. (2020) with the coefficients for type 2 AGNs. Note that \(L_{\text{bol}}\) could be lower by a factor of \(\sim 1.5\) or higher by a factor of \(\sim 7\), if \(N_H = 10^{22}\) cm\(^{-2}\) or \(10^{24}\) cm\(^{-2}\), respectively. Also, note that the bolometric correction for the hard X-ray is relatively uncertain. On the other hand, if we use the upper limit of [O III] luminosity around R1, along with a bolometric correction of 3500 (Heckman et al. 2004), we derive the upper limit of \(L_{\text{bol}} = 1.6 \times 10^{42} \text{ erg s}^{-1}\). If we assume 1% of the total [O III] in R1 is photoionized by the second AGN, we obtain \(L_{\text{bol}} = 1.6 \times 10^{42} \text{ erg s}^{-1}\). Note that the large difference between X-ray-based and [O III]-based bolometric luminosities is mainly due to various uncertain factors, including the obscuration correction factor and bolometric correction of hard X-ray luminosity as well as the uncertain fraction of the [O III] flux due to the second AGN around the R1 area.

Comparing with these estimates of bolometric luminosity, the energy outflow rate determined by the geometric approach is challenging because the kinetic energy carried by the outflow is much larger than the X-ray-based bolometric luminosity, with the kinetic coupling efficiency of \(\sim 130\). In contrast, if we adopt the [O III]-based bolometric luminosity, the efficiency is \(\sim 1.2\). On the other hand, the energy outflow rate based on the luminosity approach is at least two orders of magnitude lower than that of the geometric approach, and the kinetic coupling efficiency becomes substantially smaller. For example, if we assume 1% of the total [O III] flux in the R1 area is due to the second AGN, we obtain \(E_{\text{out}} = 2.2 \times 10^{38}\), which is \(\sim 0.015\) and \(10^{-4}\) of the X-ray-based and [O III]-based bolometric luminosities, respectively. These results are within the range of the kinetic coupling efficiencies of warm ionized gas reported in the literature (Harrison et al. 2018). Albeit with large systematic uncertainties of outflow energetics and AGN bolometric luminosity due to a number of assumptions, we find no strong evidence to rule out the scenario of outflows driven by a second AGN.

5. Conclusion

In this work, we investigate the complex kinematics of ionized gas at the central region of NGC 1068. The main results are summarized below.

1. We detect a pair of blueshifted and redshifted gas blobs, which are located in the NE region at distances of \(\sim 110\) and \(\sim 250\) pc, respectively, from the nucleus. The spatially resolved kinematics of the two gas blobs are similar but inconsistent with rotation or simple biconical outflows launched from the central AGN.

2. The center of the two gas blobs at a distance of 180 pc from the nucleus is characterized by zero velocity and high velocity dispersion to the line of sight, which are typical kinematical features of a launching point of AGN-driven gas outflows. Also, the pair of gas blobs shows kinematically similar morphology in the velocity map and shares a consistent radial velocity structure with an increasing and decreasing trend, implying that these outflows are launched by an additional (second) AGN, which is located at the midpoint of the pair.

3. High-resolution X-ray data show a putative X-ray point source near the expected position of the second AGN, while its low luminosity is not sufficient to confirm the second AGN or rule out the X-ray binary origin.

4. Based on the spatially resolved spectropolarimetric analysis, we find in the NE region a bump in the flux distribution and a significantly smaller velocity dispersion of the polarized broad Balmer line compared to that of the nucleus. These results are consistent with the scenario that there is an additional AGN at the midpoint of the two gas blobs.

Based on the multiwavelength analysis (i.e., optical and X-ray), we provide circumstantial evidence for the presence of an additional AGN. However, the analysis results are insufficient to confirm the case and there are other possibilities, i.e., X-ray binary and SN shock, responsible for the complex kinematics of ionized gas. One way to confirm the second AGN scenario is to use spectropolarimetric observations with a high spatial resolution to separate the central and additional AGNs. In turn, if the second AGN is confirmed, kinematical
characteristics such as zero velocity and high velocity dispersion of ionized gas may be used as an alternative way to search for multiple AGNs.

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