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The intriguing case of Was 49b

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Abstract. We present results of a multiwavelength study of the isolated dual AGN system Was 49. Observations show that the dominant component in this interacting system, Was 49a, is a spiral galaxy, while Was 49b is hosted in a dwarf galaxy located at 8 kpc from the nucleus of Was 49a, at the edge of its disk. The intriguing fact about this system is the luminosity of their corresponding AGNs. While Was 49a hosts a low luminosity Seyfert 2 with $L_{bol} \sim 10^{43} erg\ s^{-1}$, Was 49b has a Seyfert 2 with $L_{bol} \sim 10^{45} erg\ s^{-1}$, in the luminosity range of Quasars. Furthermore, estimates of the black hole and host galaxy masses of Was 49b indicate a black hole significantly more massive than one would expect from scaling relations. This result is in contrast with findings that the most luminous merger-triggered AGNs are found in major mergers and that minor mergers predominantly enhance AGN activity in the primary galaxy.

Keywords. galaxies: active – galaxies: bulges – galaxies: dwarf – galaxies: interactions – galaxies: nuclei – galaxies: Seyfert

1. Introduction

The dual-AGN system Was 49, first described by Bothun *et al.* (1989), is composed of a disk galaxy, Was 49a, and a dwarf galaxy, Was 49b, co-rotating in the disk of Was49a, at a projected distance of ∼8 kpc from its nucleus (Moran *et al.* 1992). While Was 49a shows signs of nuclear activity consistent with its size, a low-luminosity Seyfert 2, Was 49b hosts the most luminous AGN in this binary system, with luminosity levels typical of Quasars. Spectropolarimetric observations of Was 49b (Tran 1995) show polarized broad emission lines (Hα and Hβ) with FWHM $\sim$6000km s^{-1}, as well as a strong featureless continuum, where the stellar component is estimated to contribute $\lesssim$15% of the light. This system is also known to be relatively isolated, with Secrest *et al.* (2017) reporting the non-detection of other galaxies of similar size ($M_r \lesssim -20$mag) within a projected distance of 1Mpc.

These peculiarities of the Was 49 system make it an excellent candidate for a case study. The high luminosity of the AGN on Was 49b, combined with the low luminosity of its host, suggests that this system may not follow the usuall black hole *vs* bulge mass relations. Furthermore, the fact that the smallest component of this minor merger hosts the most luminous AGN, is contrary to empirical results, which find that minor mergers

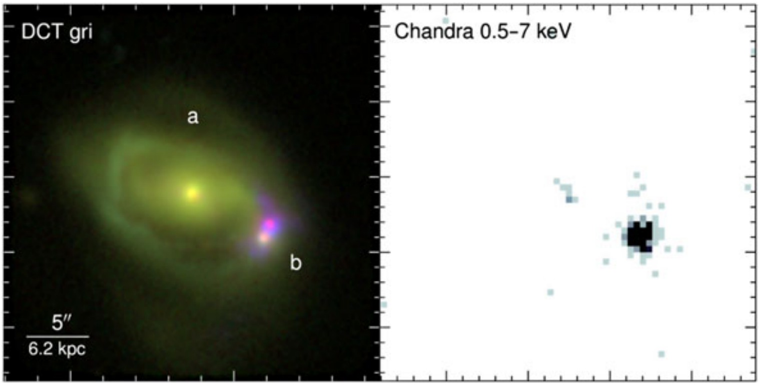

Figure 1. Optical (left) and X-ray (right) images of the Was 49 system from Secrest *et al.* (2017). The optical image is an RGB composite using images obtained with the 4.3 m Discovery Channel Telescope, using the color representation scheme from Lupton *et al.* (2004). At the redshift of Was 49 (z = 0.06328), [OIII] and Hβ fall within the g (blue) filter, the r (green) filter is predominantly continuum, and the i (red) filter contains Hα+[NII]. Note the extensive ionization region around Was 49b, which results in a pink/magenta color, indicating that the optical light is dominated by line emission. Images oriented north up, east left.

predominantly enhance the AGN activity the most massive component of the system Ellison *et al.* 2011. Here we summarize some of our previous results Secrest *et al.* 2017, and discuss some of our ongoing efforts.

2. Ground-based observations

In order to better constrain the mass of the host galaxy of Was 49b and compare this value to the mass of the black hole, we obtained deep ground-based images of this system using the 4.3 m Lowell Discovery Channel Telescope on the night of 2016 April 03. These observations were done under excellent seeing conditions (~0.5″), which allowed us to obtain images of this target in the g',r', i', z' bands, significantly deeper and much sharper than the one available in the SDSS archive (~1.4″). A color composite image is presented in Fig. 1, where we can see the structure of the system in better detail. The main galaxy, Was 49a, is a spiral galaxy with a pseudobulge and bar, as well as some morphological disturbances that can be associated with the interaction with the small companion, Was 49b. In this higher resolution image we see that the companion galaxy is split into 2 components. Given the redshift of this system, the i' image is dominated by the Hα+[NII] emission, while the r' band is dominated by continuum emission. This suggests that most of the NW component of Was 49b is due to line emission, while the SE component is a mixture of both line and continuum emission.

Using the r' image and GALFIT (Peng *et al.* 2002), we were able to decompose the surface brightness profile of this system using seven components, four for Was 49a (nucleus, bulge, disk and tidal component) and three for Was 49b (nucleus, bulge and ionized component). The results of the best fitting model can be seen in Secrest *et al.* (2017). The component that can be identified with the bulge of Was 49b has a Sérsic index $n = 1.07$, consistent with a pseudobulge, an effective radius of 1.62 kpc (1.31″) and $M_r = -19.1$ mag, consistent with a dwarf galaxy classification.

3. X-ray observations

Further evidence of the peculiarity of the Was 49 system can be seen in the right panel of Fig. 1. Here we present the *Chandra* 0.5-7 keV image, where one can see that Was 49a has very weak emission, only 7 counts in this energy band, while Was 49b is the

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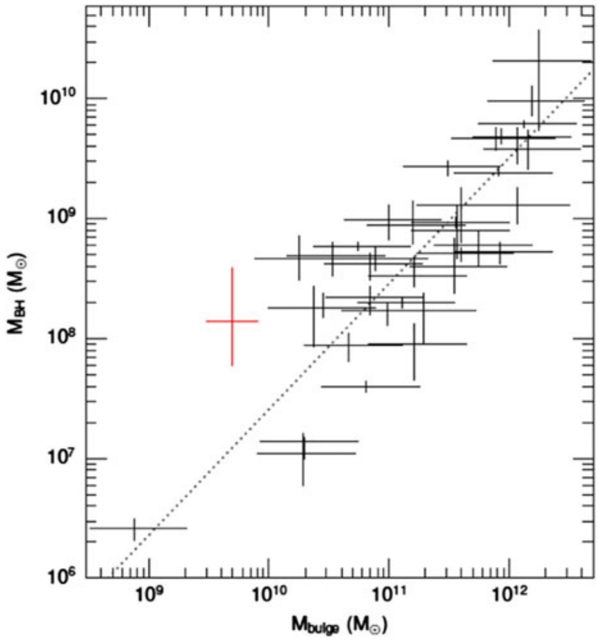

Figure 2. Black hole mass as a function of bulge mass. Data from McConnell & Ma (2013). Note that the black hole of Was 49 is overmassive relative to its bulge.

brightest component in this binary system, with 215 counts. Combining the information from *Chandra* with X-ray spectra from *NuSTAR*, *Swift BAT* and *ASCA*, we were able to fit the 0.5-195 kev spectrum of Was 49b with a power law with $\Gamma = 1.6 \pm 0.1$ and $N_H = 2.3 \times 10^{23}$, resulting in $L_{0.5-195keV} = 2.4 \times 10^{44}$ erg s^{-1}, and $L_{14-195keV} = 1.7 \times 10^{44}$erg s^{-1} (Secrest *et al.* 2017). Using the relation between L_{bol} and $L_{14-195keV}$ from Winter *et al.* (2012), we can calculate that Was 49b has $L_{bol} = 1.3 \times 10^{45}$erg s^{-1}, which puts it in the luminosity range of quasars. This high X-ray luminosity is consistent with the [OIII]λ5007Å luminosity for this source $L_{[OIII]} = 1.4 \times 10^{42}$ erg s^{-1} (Meléndez *et al.* 2008).

4. Bulge and black hole mass

The stellar mass of the bulge of Was 49b was calculated using the mass-to-light relations from Bell *et al.* (2003) and the correlation between g-r and Sérsic index n (Blanton & Moustakas 2009), given that the g band image is strongly contaminated by line emission. Based on these relations we adopted $M/L = 1.82$ and determined that the mass of the bulge of Was 49b is $5.6 \times 10^{9} M_\odot$.

Determining the black hole mass of Was 49b was complicated by the fact that this is a Seyfert 2 object. As was previously pointed out by Tran (1995) and Moran *et al.* (1992), the spectrum of this galaxy is dominated by emission lines and a mostly featureless continuum. We were able to detect a weak Ca II K line absorption on the SDSS spectrum, however, attempts to constrain the stellar velocity dispersion were unsuccessfull. In order to solve this problem we measured the FWHM of the broad Hα component on the SDSS spectrum, which originates from reflected nuclear radiation (Tran 1995), and estimated how much of the reflected continuum is due to the nucleus. Since the line-of-sight emission is heavily-obscured, we used the absorption-corrected X-ray luminosity to calculate the size of the BLR using the relation from Kaspi *et al.* (2005). This allowed us to determine a black hole mass $M_{BH} = 1.3 \times 10^{8}\ M_\odot$. In Fig. 2 we show the $M_{BH} \times M_{bulge}$ diagram,

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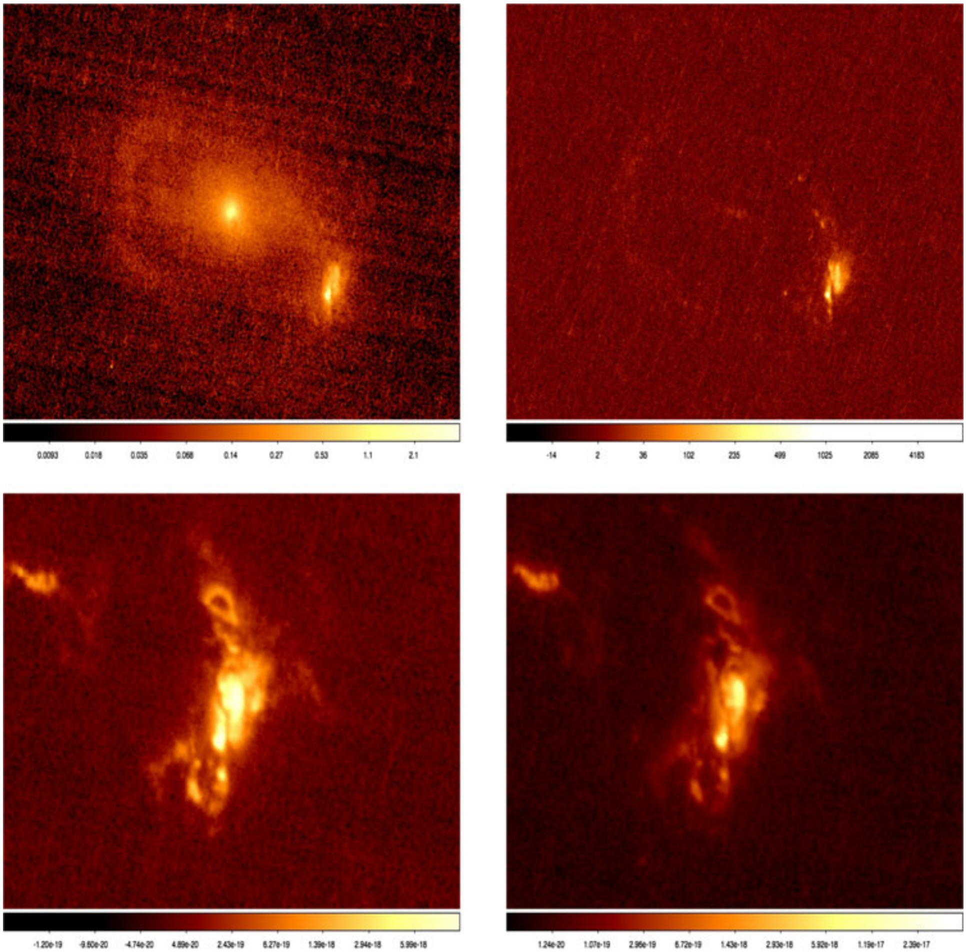

Figure 3. The top panels show the HST continuum images of the Was 49 system, rest frame V band on the left and ultraviolet λ2100Å on the right. The bottom panels show the HST emission line images. [OIII]λ5007 on the left and Hα+[NII] on the right. The images are oriented N up and East to the left. Note that the emission line images are zommed relative to the continuum ones, to better show details of the emission around the nucleus of the two galaxies.

where we can see that Was 49b has an overmassive black hole relative to its bulge mass by a factor of $\sim$20. It should be noted that our bulge mass estimate should be considered an upper limit, due to line and recombination continuum contamination to the r' filter.

5. Discussion

Was 49b is a high luminosity AGN, hosted in a dwarf galaxy. One possibility to be explored is whether this AGN is a candidate for a recoiling black hole, kicked out of the nucleus of Was 49a during coalescence (Blecha *et al.* 2011). However, such an event would also kick the black hole on Was 49a away from its nucleus, indicating that this possibility may not be applicable in this case. Another intriguing property of this system is the fact that it is a minor merger where the lowest mass component hosts the highest luminosity AGN. Simulations of coplanar gas-rich minor mergers (e.g. Callegari *et al.* 2011; Capelo *et al.* 2015) find that the secondary AGN rarely exceed a luminosity of 10^{43}erg s^{-1}. However, these simulations assume that the black hole masses of the two components

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follow the usual scaling relations. If one were to scale the mass of the secondary galaxy black holes to that of Was 49b, these simulations could reach the luminosity range of 10^{44}–10^{45} erg s^{-1}, in line with the observed values. Another interesting property of this system is its relative isolation, suggesting that Was 49b may have evolved differently. This could be either related to the way the black hole evolves relative to the bulge at high redshifts (Volonteri *et al.* 2016), or how the black hole/bulge scaling relation evolve in systems with low bulge mass (Jahnke & Macciò 2011).

6. Future work

We are currently analysing new *Hubble Space Telescope* line and continuum images of this system, as well as *Gemini* long-slit spectra, *VLA* and *VLBA* radio images. An example of some of these observations is shown in Fig. 3, where we present line free V band and ultraviolet continuum images, as well as [OIII] and Hα+[NII] images from *HST*. The V band image shows that Was 49b has a bright component, surrounded by diffuse emission, part of which can be associated with recombination continuum. The ultraviolet image shows a similar structure, as well as a ring of emission around Was 49a, which can be identified with older star forming regions, possible ignitied by the interaction between the two galaxies. The continuum images are being used to refine the bulge mass estimate. The emission line images show a large range of structure, associated with the nucleus of both Was 49a and Was 49b. The ionized gas associated with Was 49b extends for $\sim 3''$ on each side of the host galaxy, being $\sim$2 times more extended than the host galaxy itself. These observations are being combined with long-slit spectroscopic and radio continuum information to determine the origin of this gas, if it is a wind driven by the nuclues, or if it is gas in the disk of the two galaxies being ionized by Was 49b. The radio images will be used to determine the importance of the radio jets on ionizing and driving this gas. Considering the characteristics of Was 49b, overmassive black hole relative to the host, this galaxy may represent a good low-redshift surrogate to study the effects of feedback on high-redshift targets.

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