The Peculiar Case of Was 49b: An Over-Massive AGN in a Minor Merger?

Nathan Secrest
NRC Postdoctoral Fellow, U.S. Naval Research Laboratory
Henrique Schmitt (NRL), Laura Blecha (UMD), Barry Rothberg (LBT), Jacqueline Fischer (NRL)
Co-evolution of SMBHs and their host galaxies

Mergers funnel gas into the centers of galaxies (gravitational torques)

AGN “feedback” regulates star formation

Many mergers → $M_{\text{BH}}/M_{\text{bulge}}$ relation builds through central limit theorem

Kormendy & Ho (2013)
Co-evolution of SMBHs and their host galaxies

Mergers funnel gas into the centers of galaxies (gravitational torques)

Empirically, AGN enhancement with merger stage is exactly what we see!
Co-evolution of SMBHs and their host galaxies

Mergers funnel gas into the centers of galaxies (gravitational torques)

Empirically, AGN enhancement with merger stage is exactly what we see!

*Not the whole story:*

AGN enhancement depends on *stellar mass ratio*

Ellison+11
Mergers funnel gas into the centers of galaxies (gravitational torques)

Empirically, AGN enhancement with merger stage is exactly what we see!

Not the whole story:

Minor mergers enhance AGN activity in the primary galaxy
Co-evolution of SMBHs and their host galaxies

Mergers funnel gas into the centers of galaxies (gravitational torques)

Empirically, AGN enhancement with merger stage is exactly what we see!

Not the whole story:

Little enhancement seen in smaller galaxy of a minor merger
Furthermore...

The most powerful *Swift* BAT AGNs in mergers are *all* in major mergers!

Typical X-ray luminosities:

$\sim 10^{43} - 10^{44}$ erg s$^{-1}$

Koss+12
Was 49

Was 49a: AGN-hosting disk galaxy

Was 49b: Prominent ionized region 8 kpc distance from the nucleus of 49a.

One of the first serendipitously discovered dual AGN systems (Bothun et al. 1989, Moran et al. 1992)
Was 49

Was 49a: AGN-hosting disk galaxy

Was 49b: Prominent ionized region 8 kpc distance from the nucleus of 49a.

One of the first serendipitously discovered dual AGN systems (Bothun et al. 1989, Moran et al. 1992)

49b ‘sits’ on the normal disk galaxy rotation curve of 49a
What caught my eye...

Despite an enormous AGN luminosity of over $10^{45} \text{ erg s}^{-1}$ ($M_{\text{Edd}} > 10^7 M_\odot$), no hint of a stellar counterpart was found in the optical spectrum (< 15%: Tran 1995)

In Was 49, we have strong evidence for two Seyfert nuclei, since the spatially resolved emission-line strengths and ratios indicate that both nuclei emit ionizing radiation (e.g., the ionizing flux map in Fig. 11, discussed below). The rotation curve leaves no doubt that Was 49a and b are dynamically associated. The mystery of Was 49b is why it seems to have no stellar system of its own, despite being by far the more powerful AGN. Its weak, featureless continuum is consistent with scattered nonthermal emission, with no evidence of star light.

Moran+92
What caught my eye...

Despite an enormous AGN luminosity of over $10^{45}$ erg s$^{-1}$ ($M_{\text{Edd}} > 10^7 M_\odot$), no hint of a stellar counterpart was found in the optical spectrum (< 15%: Tran 1995)

However, this was years before the discovery of the $M$-$\sigma$ relation

In Was 49, we have strong evidence for two Seyfert nuclei, since the spatially resolved emission-line strengths and ratios indicate that both nuclei emit ionizing radiation (e.g., the ionizing flux map in Fig. 11, discussed below). The rotation curve leaves no doubt that Was 49a and b are dynamically associated. The mystery of Was 49b is why it seems to have no stellar system of its own, despite being by far the more powerful AGN. Its weak, featureless continuum is consistent with scattered nonthermal emission, with no evidence of star light.

Moran+92

McConnell & Ma (2013)
What caught my eye...

Despite an enormous AGN luminosity of over $10^{45}$ erg s$^{-1}$ ($M_{\text{Edd}} > 10^7 M_\odot$), no hint of a stellar counterpart was found in the optical spectrum (< 15%: Tran 1995)

However, this was years before the discovery of the M-σ relation

Quantitative galaxy morphological decomposition (e.g., GIM2D: Simard et al. 1998; GALFIT: Peng et al. 2002) not available

In Was 49, we have strong evidence for two Seyfert nuclei, since the spatially resolved emission-line strengths and ratios indicate that both nuclei emit ionizing radiation (e.g., the ionizing flux map in Fig. 11, discussed below). The rotation curve leaves no doubt that Was 49a and b are dynamically associated. The mystery of Was 49b is why it seems to have no stellar system of its own, despite being by far the more powerful AGN. Its weak, featureless continuum is consistent with scattered nonthermal emission, with no evidence of star light.

McConnell & Ma (2013)
Goals of this work:

1. Locate and characterize the stellar counterpart to the luminous AGN Was 49b

2. Determine the merger mass ratio of the Was 49 system

3. Constrain the SMBH mass in Was 49b
Black hole mass

Calculated virial mass

$L_{5100\text{Å}}/R_{\text{BLR}}$ not feasible: most of the AGN optical continuum is scattered (polarized) to an uncertain degree

Kuo+11: $L_x/R_{\text{BLR}}$ (Kaspi+05) recovers maser BH masses to within $\sim 60\%$.
Black hole mass

Calculated virial mass

$L_{5100\text{Å}}/R_{\text{BLR}}$ not feasible: most of the AGN optical continuum is scattered (polarized) to an uncertain degree

Kuo+11: $L_x/R_{\text{BLR}}$ (Kaspi+05) recovers maser BH masses to within $\sim 60\%$.

Chandra, NuSTAR, Swift:
$\sim 0.5$ - 200 keV
No significant epoch variability
$N_H = 2.3 \times 10^{23}$ cm$^{-2}$
$\Gamma = 1.6$
$L_{2-10\text{keV}} = 4 \times 10^{43}$ erg s$^{-1}$
$L_{\text{bol}} \sim 2 \times 10^{45}$ erg s$^{-1}$
Black hole mass

Calculated *virial mass*

$L_{5100\AA}/R_{\text{BLR}}$ not feasible: most of the AGN optical continuum is *scattered* (polarized) to an uncertain degree

Kuo+11: $L_x/R_{\text{BLR}}$ (Kaspi+05) recovers maser BH masses to within $\sim 60\%$.

**BOSS spectrum:**
Broad Hα:
$\text{FWHM} = 6440 \pm 100 \text{ km s}^{-1}$
Black hole mass

Calculated virial mass

$L_{5100\AA}/R_{BLR}$ not feasible: most of the AGN optical continuum is scattered (polarized) to an uncertain degree

Kuo+11: $L_x/R_{BLR}$ (Kaspi+05) recovers maser BH masses to within ~ 60%.

$M_{BH} = 1.3 \times 10^8 M_\odot (\pm 0.5 \text{ dex})$

BOSS spectrum:
Broad H$\alpha$:
FWHM = 6440 $\pm$ 100 km s$^{-1}$
Optical Observations

Observed Was 49 the Discovery Channel Telescope

4.3-meter telescope in AZ

Imaged in $ugriz$ with the Large Monolithic Imager

Seeing was $\sim 0.5''$
Optical Observations

Observed Was 49 the Discovery Channel Telescope

4.3-meter telescope in AZ

Imaged in $ugriz$ with the Large Monolithic Imager

Seeing was $\sim 0.5''$

$\sim 3$ times better resolution than Sloan!
Effect of Was 49b on its environment

\[ \begin{align*}
g & \rightarrow [\text{O} \text{III}] + \text{H} \beta \\
r & \rightarrow \text{continuum} \\
i & \rightarrow \text{H} \alpha + [\text{N} \text{II}] \\
i - g & \rightarrow [\text{O} \text{III}] / H_{\text{balmer}} \\
\end{align*} \]

AGN → stellar concentration!
NSC?
Ionized region: knots/filamentary structures,
2 kpc NW and SE of the stellar concentration
⇒ *Suggests enormous NLR*
(e.g., Schmitt+03)
Morphological decomposition

**GALFIT**

Used $r$ band to model the continuum (~6% emission line contamination)

49a: bulge + disk + nucleus

49b: bulge + nucleus

+ tidal structure
Morphological decomposition

GALFIT

Used $r$ band to model the continuum ($\sim6\%$ emission line contamination)

49a: bulge + disk + nucleus

49b: bulge + nucleus

+ tidal structure

Bulge Sersic index $n = 1.07$
(classical bulge $n \sim 4$)

$M_\star = 5.6 \times 10^9 M_\odot$ ($\pm 0.24$ dex)
Morphological decomposition

M 32
M = 7.6 \times 10^8 \, M_\odot
M_{BH} = 2.6 \times 10^6 \, M_\odot
M_{BH}/M = 0.3 \%

n = 1.07
M_\star = 5.6 \times 10^9 \, M_\odot \ (\pm 0.24 \, \text{dex})

→ 49b is a dwarf elliptical galaxy?
Morphological decomposition

\[ n = 1.07 \]
\[ M_\star = 5.6 \times 10^9 M_\odot \ (\pm 0.24 \text{ dex}) \]

→ 49b is a dwarf elliptical galaxy?

\[ M_{\text{BH}}/M_\star = 2.3\% \] suggests SMBH in Was 49b over-massive
Morphological decomposition

$M_{\text{BH}} = 1.07 M_{\bullet} = 5.6 \times 10^9 M_\odot \, (\pm 0.24 \text{ dex})$

→ 49b is a dwarf elliptical galaxy?

~ 10 - 20 times more massive than (early-type) scaling relations predict
Interpretation

Rotation curve + stellar mass ratio:

→ coplanar, minor (1:10) merger

Secondary BH grows much more than primary

However: Input BHs between $10^5$-$10^6 \, M_\odot$ (disk galaxies)

This assumption supported by data!
Interpretation

Rotation curve + stellar mass ratio:

→ coplanar, minor (1:10) merger

Secondary BH grows much more than primary

However: Input BHs between $10^5$-$10^6$ M$_\odot$ (disk galaxies)

This assumption supported by data!

Given similar Eddington ratio, stellar mass,

$10^5$-$10^6$ M$_\odot$ likely missed in the optical!
Conclusions

1. Was 49b hosts a SMBH ~ 2.3% the mass of its host
2. Despite enormous luminosity and BH mass, in a minor ~ 1:10 merger
3. Potentially yield insights into the role of minor mergers in AGN triggering

**Was 49b stats:**

- $M_{BH} = 1.3 \times 10^8 M_\odot$
- $M_\star = 5.6 \times 10^9 M_\odot$
- $L_{bol} \sim 2 \times 10^{45} \text{ erg s}^{-1}$
- $N_H = 2.3 \times 10^{23} \text{ cm}^{-2}$