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A TRIO OF MASSIVE BLACK HOLES CAUGHT IN THE ACT OF MERGING

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1. INTRODUCTION

Black holes pairs and triples are natural out comes of the hierarchical galaxy and black hole assembly process. Studies based on the SDSS galaxies show that 2% of (major) merging systems involve three galaxies (e.g., Darg et al. 2010) and only three kpc-scale triple AGN candidates are known. The galaxy **SDSS J084905.51+111447.2** at redshift z = 0.078 contains three optical stellar nuclei within a projected ~5 kpc radius with disturbed morphology, representing the first known case of a triple type-2 Seyfert nucleus. We present a comprehensive follow-up campaign including APO 3.5m/DIS spectroscopy, HST/WFC3 imaging, *Chandra* ACIS-S X-ray imaging spectroscopy and VLA radio imaging to confirm the AGN nature of triple nuclei.

2. OPTICAL AND UVIS/IR

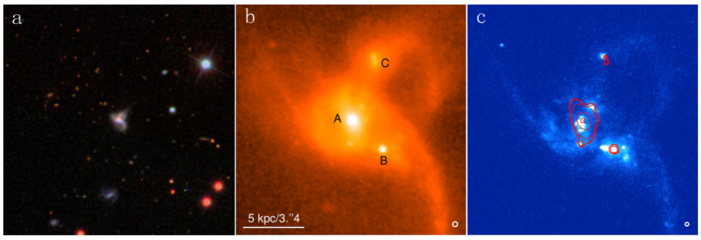
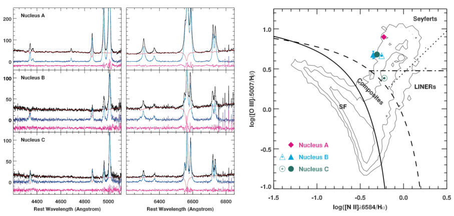


Fig1. SDSS color composite image and *HST/WFC3* IR/F105W (Y) and UVIS/F336W (U) band



We extracted 1D spectra and fitted the narrow emission lines. BPT diagram classifies all three nuclei as **type-2 Seyferts**.

We estimate the extinction correction, star formation rate based on *HST* U-band luminosity and X-ray luminosities inferred from SFR.

ID	E(B−V) (mag)	A_u (mag)	A_z (mag)	$\log L_{u,c}$ $\left(\frac{\mathrm{erg}}{\mathrm{s\,Hz}}\right)$	$SFR_{u,c}$ $\left(\frac{M_\odot}{\mathrm{yr}}\right)$	D(4000)	SFR_d $\left(\frac{M_\odot}{\mathrm{yr}}\right)$	$\log L^{SF}_{0.5-2\,\mathrm{keV}}$ (erg s^{-1})	$\log L^{SF}_{2-10\,\mathrm{keV}}$ (erg s^{-1})	$\log L^{gal}_{HX}$ (erg s^{-1})	$\log L_{[O\,III],c}$ (erg s^{-1})
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A†	0.51	2.50	0.74	29.0	8	-	-	40.57	40.61	40.49	43.10
B†	0.82	4.01	1.19	29.8	70	-	-	41.48	41.53	41.06	42.72
B‡	0.39	1.90	0.56	29.0	7	1.14	0.2	[39.0, 40.5]	[39.0, 40.5]	[39.1, 40.1]	41.66
C†	0.56	2.75	0.81	28.5	2	-	-	39.88	39.95	39.79	42.39
C‡	0.54	2.64	0.78	28.4	2	1.24	0.1	[38.7, 40.0]	[38.7, 40.0]	[39.5, 39.8]	41.63

3. X-RAY AND RADIO

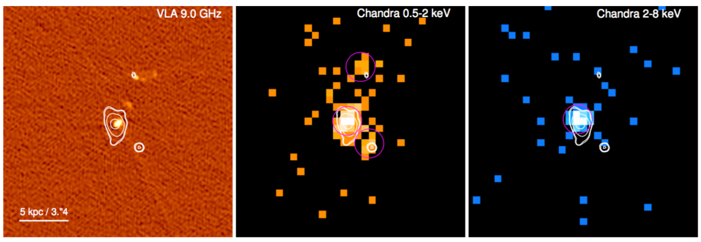


Fig2. VLA radio image and *Chandra* 0.5-2, 2-8 keV band images.

We reprocessed the Chandra data and measure the intrinsic X-ray luminosity for each nuclei. Nucleus A is detected in both soft and hard bands, whereas B and C are only detected in the soft band. Only nucleus A has sufficient counts to perform spectral analysis.

ID	Counts	$flux_{0.5-2\,\mathrm{keV}}$ (10^{-6} photons cm^{-2} s^{-1})	$flux_{2-8\,\mathrm{keV}}$	HR	Γ_X	N_H (10^{22} cm^{-2})	$\log L_{0.5-2\,\mathrm{keV}}$ (erg s^{-1})	$\log L_{2-8\,\mathrm{keV}}$ (erg s^{-1})	$\log L_{2-10\,\mathrm{keV}}$ (erg s^{-1})
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A	178.8	$6.76^{+0.74}_{-0.73}$	$6.35^{+0.73}_{-0.72}$	$-0.05^{+0.07}_{-0.07}$	$1.12^{+0.63}_{-0.48}$	$0.66^{+1.18}_{-0.66}$	$41.67^{+0.04}_{-0.04}$	$42.01^{+0.04}_{-0.05}$	$42.13^{+0.04}_{-0.05}$
B	17.7	$1.17^{+0.35}_{-0.30}$	<0.77	$-0.80^{+0.06}_{-0.16}$	-	-	$41.27^{+0.11}_{-0.13}$	<40.90	<40.99
C	8.3	$0.49^{+0.26}_{-0.21}$	<0.76	$-0.73^{+0.06}_{-0.27}$	-	-	$40.90^{+0.18}_{-0.23}$	<40.90	<40.98

With VLA A-configuration observation at 9.0 GHz, we have detected nuclei A and C and set a 3σ upper limit for nucleus B. We extrapolate our VLA 9.0 GHz measurements to 1.4 GHz to estimate lower radio-based SFR.

ID	$S^{Peak}_{9.0\,\mathrm{GHz}}$ (mJy/beam)	$S^{Int}_{9.0\,\mathrm{GHz}}$ (mJy)	$\log L_{9.0\,\mathrm{GHz}}$ (erg s^{-1} Hz^{-1})	$\log L_{1.4\,\mathrm{GHz}}$ (erg s^{-1} Hz^{-1})	$\log L^{SF}_{1.4\,\mathrm{GHz}}$ (erg s^{-1} Hz^{-1})	$SFR_{1.4\,\mathrm{GHz}}$ ($M_\odot$ yr^{-1})
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	2.58	5.52±0.17	30.09	30.49	$\lesssim$29.49	$\lesssim$20
B	<0.018	<0.018	<27.61	<28.08	<28.08	<0.8
C	0.348	0.472±0.014	29.03	29.43	$\lesssim$28.43	$\lesssim$2

4. NATURE OF NUCLEAR IONIZING SOURCES

- Nucleus A is detected as a compact point source in both soft and hard X-ray bands. The high hard X-ray luminosity, particularly when compared to its moderate SFR, unambiguously confirms A as an AGN.
- Nucleus C is detected as a compact radio source by VLA in 9.0 GHz, while it is undetected in the hard X-ray. The expected soft X-ray luminosity from pure star formation related processes is an order of magnitude smaller than the total soft X-ray luminosity. Thus it confirms C as an AGN
- While Nucleus B is neither detected in the hard X-rays nor in the radio, its soft X-ray luminosity exceeds that would be expected from pure star formation related processes driven from both *HST* U-band and radio luminosity. In addition, photoionization in favor of an additional AGN in B, rather than being solely ionized by A and/or C.

5. DISCUSSIONS

- By modeling host galaxy photometry and internal dust extinction of SDSS J0849+1114, we have estimated the stellar masses of the three merging components to be ~$10^{11.3} M_\odot$, $10^{10.0} M_\odot$, and $10^{10.5} M_\odot$ for A, B, and C. Assuming the empirical correlation between black hole mass and host total stellar mass observed in local broad-line AGN (Reines & Volonteri 2015), the inferred black hole masses are ~$10^{7.5} M_\odot$, $10^{6.4} M_\odot$, and $10^{6.7} M_\odot$, consistent with independent estimates based on host galaxy stellar velocity dispersion within uncertainties.
- Using a simple stellar dynamical friction argument, we have estimated that the trio in SDSS J0849+1114 may form a bound MBH triple in < 2 Gyr.

6. SUMMARY

By conducting new, spatially resolved optical spectroscopy, we have classified all three nuclei as type-2 Seyferts based on the classical BPT diagram.

Our comprehensive observations, including *Chandra* X-ray imaging spectroscopy, *HST* U- and Y-band imaging and VLA radio imaging, strongly suggest that all three nuclei are AGN, making SDSS J0849+1114 the first most unambiguous case known to host a kpc-scale **trio of massive black holes**.

Similar systems may be more common in the early universe when galaxy mergers are thought to be more frequent.

ACKNOWLEDGEMENTS

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