

UCLA

UCLA Previously Published Works

Title

A High-resolution Search for Dual Active Galactic Nucleus Candidates in Mergers: A Preselection Strategy Using Keck Adaptive Optics

Permalink

<https://escholarship.org/uc/item/8vb8179v>

Journal

The Astrophysical Journal, 1006(2)

ISSN

0004-637X

Authors

Vazquez, Camilo

Satyapal, S

Canalizo, G

et al.

Publication Date

2026-08-01

DOI

10.3847/1538-4357/ae7a4b

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed



A High-resolution Search for Dual Active Galactic Nucleus Candidates in Mergers: A Preselection Strategy Using Keck Adaptive Optics

Camilo Vazquez^{1,21}, S. Satyapal¹, G. Canalizo², N. J. Secrest³, R. W. Pfeifle³, T. Bohn⁴, K. Nyland³, A. Aravindan^{5,6}, L. Blecha⁷, Jenna M. Cann^{8,9,10}, S. Doan¹, E. K. S. Hicks¹¹, P. Kurczynski¹², S. Juneau¹³, M. Malkan¹⁴, M. McDonald², J. McKaig^{8,15,22}, P. Nair¹⁶, B. Rothberg^{1,3}, F. Muller-Sanchez¹⁷, E. Schwartzman¹⁸, R. Sexton^{1,3}, and V. U^{19,20}

¹ Department of Physics and Astronomy, George Mason University, MS3F3, 4400 University Drive, Fairfax, VA 22030, USA; cvazquez4@gmu.edu

² Department of Physics and Astronomy, University of California, Riverside, 900 University Avenue, Riverside, CA 92521, USA

³ U.S. Naval Observatory, 3450 Massachusetts Avenue NW, Washington, DC 20392-5420, USA

⁴ Research Center for Space and Cosmic Evolution, Ehime University, Bunkyo-cho 2-5, Matsuyama, Ehime 790-8577, Japan

⁵ Department of Astronomy, The University of Texas at Austin, Austin, TX 78712, USA

⁶ Cosmic Frontier Center, The University of Texas at Austin, Austin, TX 78712, USA

⁷ Department of Physics, University of Florida, 2001 Museum Rd., Gainesville, FL 32611, USA

⁸ X-ray Astrophysics Laboratory, NASA Goddard Space Flight Center, Code 662, Greenbelt, MD 20771, USA

⁹ Center for Space Science and Technology, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA

¹⁰ Center for Research and Exploration in Space Science and Technology, NASA/GSFC, Greenbelt, MD 20771, USA

¹¹ Department of Physics and Astronomy, University of Alaska Anchorage, Anchorage, AK 99508-4664, USA

¹² Astrophysics Science Division Code 660, NASA Goddard Space Flight Center, Greenbelt, MD 207781, USA

¹³ NSF's National Optical-Infrared Astronomy Research Laboratory, 950 N. Cherry Avenue, Tucson, AZ 85719, USA

¹⁴ Department of Physics & Astronomy, 430 Portola Plaza, University of California, Los Angeles, CA 90095, USA

¹⁵ Oak Ridge Associated Universities, NASA NPP Program, Oak Ridge, TN 37831, USA

¹⁶ Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, AL 35487, USA

¹⁷ Department of Physics and Materials Science, The University of Memphis, 3720 Alumni Avenue, Memphis, TN 38152, USA

¹⁸ U.S. Naval Research Laboratory, 4555 Overlook Ave. SW, Washington, DC 20375, USA

¹⁹ IPAC, Caltech, 1200 E. California Blvd., Pasadena, CA 91125, USA

²⁰ Department of Physics and Astronomy, 4129 Frederick Reines Hall, University of California, Irvine, CA 92697, USA

Received 2025 June 23; revised 2026 May 28; accepted 2026 June 5; published 2026 July 30

Abstract

Accreting supermassive black holes (SMBHs) in galaxy mergers with separations <1 kpc are crucial for understanding SMBH growth, galaxy evolution, and SMBH binary evolution. Despite their importance, few are known, and most have been discovered serendipitously. In this work, we develop and test a method to systematically preselect advanced mergers likely to contain unresolved subkiloparsec nuclear substructure and dual active galactic nucleus (AGN) candidates for follow-up spectroscopy. By exploiting the survey area and astrometric precision of the Wide-field Infrared Survey Explorer (WISE) and the Sloan Digital Sky Survey (SDSS), we identify 46 advanced mergers that have red WISE colors ($W_1 - W_2 > 0.5$) indicative of accretion activity and significant subarcsecond offsets between their optical and infrared coordinates. We conduct high-resolution adaptive optics observations with the Keck Near Infrared Camera 2 in the K_p band ($2.124 \mu\text{m}$, $\Delta\lambda = 0.351 \mu\text{m}$) to search for unresolved substructure suggested by these offsets. We find that 20/46 (43.5%) of the sample show substructure tracing the SDSS/WISE offset. When restricted to detections of compact nuclear components with separations <3 kpc, we achieve a detection rate of 34.8%, a higher yield than previous preselection techniques, such as double-peaked [O III] or hard-X-ray selection. These results demonstrate that the SDSS/WISE offset method provides an efficient pathway for identifying late-stage mergers and dual-AGN candidates for spectroscopic confirmation. Archival optical Hubble Space Telescope imaging reveals that substructure identified with Keck is often missed in the optical or erroneously identified, due to partial obscuration, underscoring the importance of infrared studies of late-stage mergers.

Unified Astronomy Thesaurus concepts: Active galactic nuclei (16); Galaxy mergers (608); Interacting galaxies (802); Adaptive optics (2281); Infrared astronomy (786); Infrared telescopes (794)

1. Introduction

Galaxy mergers play a fundamental role in shaping the growth of supermassive black holes (SMBHs) and the

evolution of their host galaxies. During the late stages of a merger, when the two galactic nuclei reach subkiloparsec separations, gravitational torques efficiently drive gas inflows toward the nuclear regions, triggering intense star formation and accretion onto the central SMBHs (S. Van Wassenhove et al. 2012; P. R. Capelo et al. 2015, 2017; L. Blecha et al. 2018; N. Chen et al. 2023a). At these separations, both SMBHs are theoretically expected to be actively accreting, forming a dual active galactic nucleus (AGN; L. Blecha et al. 2018). Dual AGNs trace a critical phase of SMBH growth and represent the immediate progenitors of bound SMBH binaries, which ultimately merge and generate low-frequency

²¹ Presidential Scholar.

²² NASA Postdoctoral Program Fellow.



gravitational waves (D. Merritt & M. Milosavljević 2005). Constraining the occurrence and properties of mergers at subkiloparsec separations is therefore essential for understanding SMBH growth, galaxy evolution, and SMBH binary formation.

Despite their importance, dual accreting SMBHs remain extremely rare observationally, with most systems discovered serendipitously. Due to the angular resolution limits of the available search techniques, the current sample of confirmed systems is heavily biased toward nuclear separations >1 kpc (A. De Rosa et al. 2019; R. W. Pfeifle et al. 2025, and references therein). Only a small number of dual AGNs are known at projected separations below 10 kpc (e.g., S. Bianchi et al. 2008; H. Fu et al. 2011b; M. Koss et al. 2012; X. Liu et al. 2013; J. M. Comerford et al. 2015; F. Müller-Sánchez et al. 2015; S. Satyapal et al. 2017; M. Hou et al. 2019; R. W. Pfeifle et al. 2019b), and only a handful have been identified at subkiloparsec separations (e.g., S. Komossa et al. 2003; V. U et al. 2013; F. Müller-Sánchez et al. 2015; K. Iwasawa et al. 2018; K. T. Voggel et al. 2022; M. J. Koss et al. 2023). With such a small and heterogeneously selected sample, the frequency and properties of dual AGNs at separations <1 kpc remain poorly constrained (R. W. Pfeifle et al. 2025). These constraints are critical for improving predictions of the SMBH merger rates detectable by pulsar timing array experiments such as NANOGrav (G. Agazie et al. 2023). In particular, the efficiency of dynamical friction at separations between ~ 1 kpc and ~ 0.1 kpc plays a key role in setting SMBH merger timescales (L. Z. Kelley et al. 2017; K. Li et al. 2021, 2022).

Detecting late-stage mergers at subkiloparsec separations is, however, observationally challenging. The spatial resolution required to directly resolve such systems is beyond the reach of large-area optical surveys such as the Sloan Digital Sky Survey (SDSS; K. N. Abazajian et al. 2009), which are seeing-limited. Even very long baseline interferometry (VLBI) is incapable of directly identifying SMBH binaries at parsec and subparsec separations in large samples. As a result, the dual-AGN population at separations below ~ 1 kpc remains statistically unconstrained.

To overcome these spatial-resolution limitations, a variety of indirect techniques have been developed to identify closely separated late-stage mergers and potential dual AGNs. One widely used approach relies on the detection of double-peaked [O III] $\lambda 5007$ emission in SDSS spectra, which has been proposed as a signature of the orbital motion of kiloparsec-scale dual SMBHs (e.g., J.-M. Wang et al. 2009; X. Liu et al. 2010b; K. L. Smith et al. 2010; J.-Q. Ge et al. 2012; Y. Lyu & X. Liu 2016; J. M. Comerford et al. 2018; D. C. Kim et al. 2020; D. Maschmann et al. 2020). However, high-spatial-resolution follow-up studies have shown that only a small fraction ($\sim 2\%$) of such systems host bona fide dual AGNs, with the majority of double-peaked profiles arising from outflows or rotating narrowline regions associated with single AGNs (e.g., X. Liu et al. 2010a, 2013; D. J. Rosario et al. 2010; J. M. Comerford et al. 2011, 2013, 2015; H. Fu et al. 2011a, 2011b, 2012; Y. Shen et al. 2013; R. C. McGurk et al. 2015; F. Müller-Sánchez et al. 2015).

A complementary strategy exploits Gaia’s high-precision astrometry to search for unresolved dual AGNs through “varstrometry,” in which variability-induced shifts in the photocenter signal the presence of multiple accreting sources

(e.g., Y. Shen et al. 2019; H.-C. Hwang et al. 2020; Y.-C. Chen et al. 2022, 2023b; F. Mannucci et al. 2023; H.-C. Wang et al. 2023; E. Schwartzman et al. 2024; A. Uppal et al. 2024). While theoretically capable of resolving pair separations down to ~ 10 pc (H.-C. Hwang et al. 2020), in practice this method has only identified kiloparsec-scale confirmed dual AGNs. Additionally, this method is limited by its sensitivity to optical obscuration and depends strongly on parameters such as flux ratios, variability amplitudes, and projected separations. Another Gaia-based approach is the Gaia Multi-Peak (GMP) method, which uses multiple peaks in the Gaia window data to identify candidate dual AGNs, and is expected to be most effective at identifying systems with projected separations larger than a few kiloparsecs (F. Mannucci et al. 2023). Enhanced obscuration is both theoretically predicted and observationally common in late-stage mergers (P. F. Hopkins & L. Hernquist 2006; G. F. Snyder et al. 2013; S. Satyapal et al. 2014; C. Ricci et al. 2017; L. Blecha et al. 2018; E. Treister et al. 2018), further reducing the completeness of optical astrometric techniques.

An alternative and complementary approach is to exploit the all-sky coverage of the Wide-field Infrared Survey Explorer (WISE; E. L. Wright et al. 2010) to identify obscured AGNs in merging systems. Importantly, simulations predict that red mid-infrared (MIR) AGN colors in mergers emerge preferentially in the late stages of the interaction, when nuclear separations have decreased to scales where dual AGNs are most likely to be triggered (L. Blecha et al. 2018). In earlier merger phases, enhanced star formation dominates the MIR emission and dilutes the AGN contribution, preventing such systems from satisfying MIR AGN color criteria. This picture is supported observationally by Chandra follow-up studies, which show that MIR-selected AGNs in mergers are preferentially late-stage systems, including confirmed and candidate dual AGNs (S. Satyapal et al. 2017; R. W. Pfeifle et al. 2019a, 2019b).

In this work, we combine MIR AGN color selection with subarcsecond astrometric offsets between optical and infrared centroids measured by SDSS and WISE to develop a systematic preselection strategy for identifying late-stage mergers likely to host unresolved subkiloparsec nuclear substructure. Although neither SDSS nor WISE can directly resolve nuclei separated by less than $\sim 1.5''$, their astrometric precision enables the detection of positional offsets that trace unresolved structure in merging systems. We refer to these positional discrepancies as SDSS/WISE offsets. Using this approach, we identify a sample of 194 nearby ($z < 0.244$) highly disturbed mergers with MIR colors indicative of accretion activity and significant SDSS/WISE offsets.

We present high-resolution adaptive optics (AO) imaging of 46 such systems obtained with the Keck Near Infrared Camera 2 (NIRC2)²³ in the K_p band. The goal of this paper is to test the effectiveness of the SDSS/WISE offset method by quantifying how often it successfully identifies unresolved subkiloparsec substructure in late-stage mergers. While the ultimate scientific motivation of this work is to enable the discovery of closely separated dual AGNs, confirmation of AGN multiplicity requires spatially resolved spectroscopy and is beyond the scope of this paper. Such follow-up will be presented in future work.

²³ <https://www2.keck.hawaii.edu/inst/nirc2/>

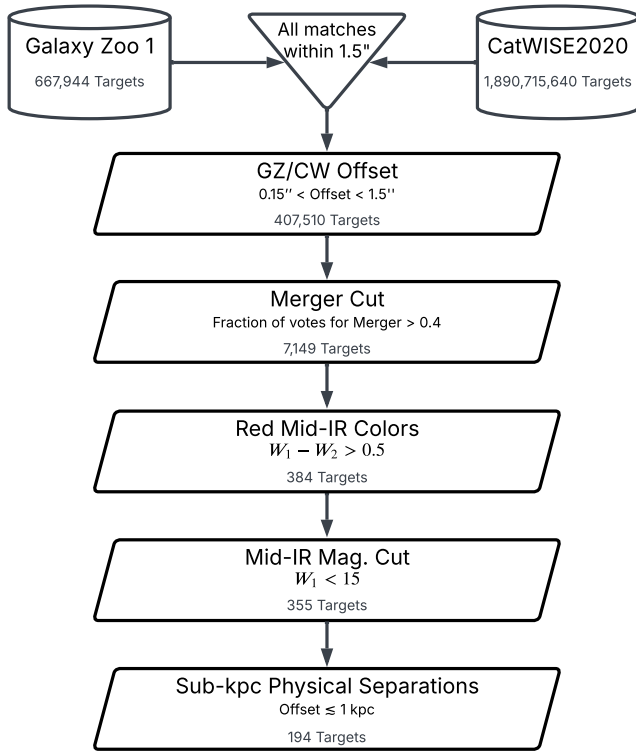


Figure 1. Selection steps used to construct the SDSS/WISE merger parent sample. Starting from Galaxy Zoo DR1 and CatWISE2020, we select highly disturbed mergers with red WISE colors, reliable WISE photometry, and significant SDSS/WISE positional offsets ($0.15'' < \text{offset} < 1.5''$). The final parent sample contains 194 systems for which the observed SDSS/WISE angular offset corresponds to a projected physical separation $\lesssim 1$ kpc, computed individually using each galaxy’s redshift. The parent sample spans $0.0002 < z < 0.2438$.

This paper is organized as follows. In Section 2, we describe the sample selection and SDSS/WISE offset methodology. Section 3 presents the Keck/NIRC2 observations and data reduction. In Section 4, we analyze the NIRC2 images and evaluate the performance of the offset selection technique. We summarize our conclusions in Section 5. Throughout this paper, we assume a Λ CDM cosmology with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$.

2. Sample Selection

The goal of this work is to test whether SDSS/WISE astrometric offsets in disturbed galaxy mergers reliably trace unresolved near-infrared (NIR) substructure associated with late-stage mergers and potential dual-AGN hosts. To do so, we construct a hierarchical set of samples drawn from a common parent population and observed with different datasets, each designed to robustly test the reliability of the offset selection method in identifying subarcsecond substructure unresolved by both SDSS and WISE. In this section, we describe: (i) the construction of the parent merger sample; (ii) the primary Keck AO sample used for high-resolution validation; (iii) an expanded-offset sample incorporating UKIRT Infrared Deep Sky Survey (UKIDSS) imaging to test offset behavior and establish its reliability over a wider range of angular separations; and (iv) comparison samples used to assess the role of merger status and astrometric offsets in identifying subarcsecond substructure identified in Keck AO data. A schematic overview of the selection steps is shown in Figure 1.

The general properties of our primary Keck AO sample are listed in Table 1, and a summary of all samples and their relationships is provided in Table 2.

2.1. Parent Merger Sample and Primary Keck AO Merger Sample

We begin by constructing a parent sample of likely galaxy mergers using the Galaxy Zoo DR1 catalog (C. J. Lintott et al. 2008), which provides visual classifications of morphologically disturbed systems. The full sequence of selection steps is summarized schematically in Figure 1. We crossmatch all Galaxy Zoo targets with the CatWISE2020 catalog (F. Marocco et al. 2021) using a $1.5''$ matching radius, where the Galaxy Zoo positions are derived from SDSS DR7. To ensure that the SDSS/WISE positional offsets probe the late-stage merger regime that remains largely unexplored observationally, we require the angular SDSS/WISE offsets for each system to correspond to projected physical separations $\lesssim 1$ kpc.

From this matched catalog, we select systems satisfying the following criteria:

1. a high likelihood of being a merger, based on the Galaxy Zoo’s weighted merger vote fraction parameter, f_m , where $f_m > 0.4$ indicates a system is a strong merger candidate (D. W. Darg et al. 2010);
2. red MIR colors ($W_1 - W_2 > 0.5$), indicative of accretion activity in mergers (L. Blecha et al. 2018);
3. robust CatWISE2020 detections with $W_1 < 15$; and
4. significant SDSS/WISE positional offsets in the range $0.15'' < \text{offset} < 1.5''$.

The upper limit of the offset range corresponds to the approximate spatial resolution of SDSS, while the lower limit is set by the minimum detectable offset between SDSS DR7 and CatWISE2020, which depends on both the astrometric and centroiding uncertainties of each survey. The reported SDSS DR7 statistical and systematic per-coordinate uncertainties are ≈ 45 mas and ≈ 20 mas, respectively (K. N. Abazajian et al. 2009), giving $\sigma_{\text{SDSS,astrom.}} \approx 49$ mas when combined in quadrature. For CatWISE2020, F. Marocco et al. (2021) report an astrometric floor of ≈ 50 mas and systematic offsets of ≈ 46 and ≈ 32 mas in R.A. and decl., respectively, resulting in $\sigma_{\text{WISE,astrom.}} \approx 90$ mas.

We estimate the upper limits of the centroiding uncertainties as $0.685 \times \text{FWHM}/\text{signal-to-noise ratio (SNR)}$, appropriate for seeing-limited observations with a Moffat point-spread function (PSF; I. R. King 1983; T. Fritz et al. 2010; M. Vakili & D. W. Hogg 2016). Adopting an SDSS FWHM of $1.5''$ (K. N. Abazajian et al. 2009) and a sample median r-band SNR of 53 gives $\sigma_{\text{SDSS,cent.}} \approx 19$ mas, and a WISE FWHM of $6''$ (D. Stern et al. 2012) and a sample median W_1 SNR of 43 gives $\sigma_{\text{WISE,cent.}} \approx 96$ mas. Combining the astrometric and centroiding uncertainties in quadrature yields total positional uncertainties of $\sigma_{\text{SDSS}} \approx 53$ mas and $\sigma_{\text{WISE}} \approx 131$ mas, resulting in a combined total uncertainty of $\sigma_{\text{SDSS/WISE}} \approx 142$ mas. We therefore adopt a conservative minimum offset threshold of 150 mas to ensure the offsets are significant and resolvable with Keck AO imaging.

The $W_1 < 15$ magnitude cut ensures high-reliability CatWISE2020 detections, for which the completeness and positional accuracy exceed $\sim 98\%$ (F. Marocco et al. 2021), and minimizes spurious offsets arising from low-SNR centroid measurements. The requirement for red WISE colors further

Table 1

General Properties of the Primary Keck AO Merger Sample, Consisting of 46 Advanced Mergers Selected from the SDSS/WISE Offset Parent Sample and Observed with Keck AO Imaging

SDSS Name	Name	R.A. (deg)	Decl. (deg)	$W_1 - W_2$ (mag)	Offset (arcsec)	z	$E(B - V)$ (mag)	Optical Class	Morph.
J001707.95+011506.3	...	4.283	1.252	1.014	0.511	0.106	1.021	AGN	1
J010942.21-004417.4	...	17.426	-0.738	0.713	0.443	0.089	0.486	Comp.	1
J013720.02+005722.2	...	24.333	0.956	0.514	0.280	0.198	0.832	Comp.	3
J015028.40+130858.4	...	27.618	13.150	1.258	0.275	0.147	0.299	SF	2
J033037.40-003304.0	...	52.656	-0.551	0.552	0.169	0.147	0.470	N/A	0
J082312.61+275139.8	...	125.803	27.861	0.972	0.294	0.168	0.659	Comp.	2
J083824.00+254516.3	NGC 2623	129.600	25.755	0.718	0.912	0.018	1.190	AGN	0
J084344.98+354942.0	...	130.937	35.828	0.709	0.387	0.054	0.438	AGN	0
J090025.37+390353.7	IRAS 08572+3915	135.106	39.065	2.293	0.510	0.058	0.858	Comp.	0
J091529.62+090601.5	...	138.873	9.100	1.439	0.431	0.143	0.662	AGN	3
J093314.80+630945.0	...	143.312	63.163	0.822	0.167	0.118	0.564	AGN	1
J093551.60+612111.3	UGC 5101	143.965	61.353	1.695	0.318	0.040	1.418	AGN	0
J101653.82+002857.0	...	154.224	0.483	1.082	0.275	0.116	0.185	AGN	2
J101833.64+361326.6	...	154.640	36.224	0.663	0.189	0.054	0.496	AGN	0
J105705.40+580437.4	VII Zw 353	164.273	58.077	0.606	0.308	0.140	0.064	Comp.	0
J110213.01+645924.8	...	165.554	64.990	1.193	0.276	0.078	0.742	AGN	1
J111519.98+542316.7 ^a	MCG +09-19-015 NED02	168.833	54.388	0.790	0.294	0.070	0.671	AGN	0
J120149.75-015327.5	...	180.457	-1.891	0.574	0.316	0.091	0.499	AGN	0
J120408.82+132117.0	UGC 7043	181.037	13.355	0.546	0.486	0.076	0.744	AGN	1
J121522.77+414620.9	...	183.845	41.773	0.901	0.321	0.196	0.271	AGN	0
J123915.40+531414.6 ^b	...	189.814	53.237	0.599	0.306	0.202	0.396	AGN	1
J124046.40+273353.6 ^a	KUG 1238+278A	190.193	27.565	1.103	0.315	0.057	0.889	Comp.	0
J124117.64+273252.3	...	190.324	27.548	0.598	0.411	0.140	0.685	Comp.	2
J124136.22+614043.4	...	190.401	61.679	0.746	0.259	0.135	0.538	AGN	2
J124406.61+652925.2	...	191.028	65.490	0.794	0.537	0.107	0.612	AGN	0
J131517.26+442425.5 ^c	MRK 248	198.822	44.407	1.142	0.689	0.036	0.580	Comp.	1
J131535.06+620728.6 ^d	UGC 8335B	198.896	62.125	0.762	0.585	0.031	0.659	Comp.	3
J131701.41+004509.7	...	199.256	0.753	0.682	0.187	0.138	0.479	AGN	0
J132035.40+340821.5 ^d	UGC 8387	200.148	34.139	0.687	1.209	0.023	1.265	Comp.	1
J133032.00-003613.5	VIII Zw 318	202.634	-0.604	0.578	0.300	0.054	0.585	AGN	3
J134442.16+555313.5 ^c	MRK 273	206.176	55.887	1.165	0.799	0.037	1.031	AGN	1
J134651.82+371231.0	...	206.716	37.209	0.692	0.230	0.215	0.440	AGN	3
J135255.67+252859.6	KUG 1350+257	208.232	25.483	0.686	0.198	0.064	0.276	SF	0
J135429.05+132757.2 ^a	...	208.621	13.466	1.016	0.184	0.063	0.117	AGN	0
J135646.10+102609.0 ^b	...	209.192	10.436	1.347	0.258	0.123	0.213	AGN	1
J142742.68+050318.4	...	216.928	5.055	0.764	0.400	0.159	0.571	AGN	0
J150517.88+080912.7	...	226.325	8.154	0.923	0.194	0.039	0.779	Comp.	2
J151747.47+334740.4	...	229.448	33.795	0.704	0.494	0.119	0.493	AGN	0
J151806.13+424445.0	VV 705 NED01	229.526	42.746	0.629	0.500	0.040	0.891	Comp.	2
J151907.33+520606.0	SBS 1517+522	229.781	52.102	1.066	0.332	0.138	0.705	AGN	0
J152659.44+355837.0	IRAS 15250+3609	231.748	35.977	1.437	0.376	0.055	0.452	Comp.	2
J153142.10+051801.6	...	232.925	5.300	0.617	0.232	0.123	N/A	Comp.	0
J153954.78+272758.7	...	234.978	27.466	0.847	0.267	0.119	0.723	AGN	0
J161708.95+222627.9	...	244.287	22.441	0.872	0.672	0.066	0.484	AGN	0
J163115.52+235257.5 ^a	...	247.815	23.883	0.736	0.168	0.059	0.521	AGN	0
J165306.55+262638.0	...	253.277	26.444	1.087	0.261	0.119	0.340	AGN	0

Notes. These targets form the core dataset used to evaluate whether SDSS/WISE astrometric offsets reliably trace unresolved NIR substructure at subkiloparsec scales. Optical classifications are based on the BPT criteria of L. J. Kewley et al. (2001) and G. Kauffmann et al. (2003b). The “Morph.” column indicates NIR morphology as defined in Section 4.1—(0) a single nucleus; (1) dual nuclei; (2) a compact secondary source consistent with an SF region; or (3) prominent spiral arms or tidal features. The superscripts indicate archival Keck observations from previous programs.

^a Koss (H230N2L, H208N2L).

^b Djorgovski (C304N2L).

^c Urry (Y076).

^d Ryder (Z229).

^e Max (U063N2L).

enhances the likelihood that the systems host dust-heated nuclear emission, which may be associated with obscured AGN activity. While MIR color selection alone is not sufficient to uniquely identify AGNs—particularly at the relatively inclusive threshold adopted here ($W_1 - W_2 > 0.5$),

where contamination from star-forming (SF) galaxies is expected (D. Stern et al. 2012; R. J. Assef et al. 2013, 2018)—the color cut serves as an efficient preselection for dusty, late-stage mergers. When combined with the SDSS/WISE positional offset criterion, this approach preferentially selects systems with

Table 2
Summary of Samples Analyzed in This Work and Their Roles in Testing the SDSS/WISE Offset Method

Sample Name	Imaging	Merger	Offset Range ^a	N	HST Imaging	Substructure ^b	Major ^c
Primary and Extended Merger Samples							
Primary Keck AO Merger Sample ^d	Keck AO	$f_m > 0.4$	$0''.15 < \Delta_{\text{off}} < 1''.5$	46	16 (35%)	20 (43%)	10 (22%)
Expanded Keck AO Merger Sample	Keck AO	$f_m > 0.4$	$0''.15 < \Delta_{\text{off}} < 6''$	53	18 (34%)	25 (47%)	...
UKIDSS Merger Sample	UKIDSS	$f_m > 0.4$	$0''.8 < \Delta_{\text{off}} < 6''$	61	6 (10%)	46 (75%)	...
Comparison Samples							
Keck Nonmerger Comparison Sample ^d	Keck AO	$f_m < 0.4$	$0''.15 < \Delta_{\text{off}} < 1''.5$	40	13 (33%)	10 (25%)	7 (18%)
Keck Nonoffset Comparison Sample	Keck AO	$f_m > 0.4$	$\Delta_{\text{off}} < 0''.15$	11	0 (0%)	1 (9%)	0 (0%)

Notes. All samples satisfy $W_1 < 15$ and $W_1 - W_2 > 0.5$. The Primary Keck AO Merger Sample is the core dataset used to quantify unresolved NIR substructure at projected separations $\lesssim 1$ kpc. The Expanded Keck AO Merger Sample, a superset of the Primary Keck AO Merger Sample, extends the offset range to $6''$ and is used to test whether the offset–substructure connection persists beyond the subkiloparsec regime. The UKIDSS Merger Sample uses UKIDSS imaging (with reliable absolute astrometry) to verify whether SDSS/WISE offsets trace resolved NIR structure over a wider range of separations. Comparison samples modify either the merger classification or the offset requirement while keeping the MIR selection fixed. Note that the Expanded Keck AO Merger Sample includes the 46 targets in the Primary Keck AO Merger Sample.

^a Δ_{off} denotes the SDSS/WISE astrometric offset.

^b See Section 4.1 for the definition of substructure.

^c The fraction of systems with nuclear K_p -band flux ratios consistent with major mergers (Section 3.1); reported only for samples with Keck AO imaging.

^d SDSS/WISE offsets correspond to projected physical separations $\lesssim 1$ kpc.

unresolved and potentially obscured nuclear structure that are strong candidates for hosting accreting SMBHs.

Applying these criteria yields 355 highly disturbed mergers with red MIR colors and statistically significant optical–infrared centroid offsets. From this set, we define the SDSS/WISE merger parent population by selecting systems with projected SDSS/WISE physical separations $\lesssim 1$ kpc, computed on a per-object basis from their redshifts, resulting in 194 merger systems spanning a redshift range of 0.0002–0.2438. These offsets are measurable because both SDSS and CatWISE2020 provide high astrometric precision, even when the nuclei themselves remain unresolved. In such cases, positional discrepancies between the optical and infrared centroids can arise from unresolved dual nuclei, compact nuclear star clusters, or obscured accreting SMBHs, making this parent population an ideal starting point for testing whether SDSS/WISE offsets trace previously unresolved substructure.

From this parent population, we select targets suitable for Keck AO observations based on the availability of nearby tip-tilt stars with R-band magnitudes < 19 and angular separations $\lesssim 30''$. This results in 36 systems observed with Keck/NIRC2 as part of this program. We additionally identify 10 mergers in the Keck archive that satisfy the same parent-sample selection criteria, yielding a total Primary Keck AO Merger Sample of 46 systems. These systems form the core sample used to directly test whether SDSS/WISE positional offsets trace previously unresolved NIR substructure at subkiloparsec scales.

We note that the inclusion of archival Keck targets may introduce modest selection biases, as archival observations can preferentially target systems with distinctive morphologies or enhanced nuclear activity. However, all archival targets satisfy the same parent-sample selection criteria and therefore provide a consistent extension of the primary sample for evaluating the offset selection methodology.

Galaxies in our sample are classified as AGNs or SF galaxies based on their optical narrow emission-line ratios, using the Baldwin–Philips–Terlevich (BPT) diagram

(J. A. Baldwin et al. 1981). Classifications follow the criteria of G. Kauffmann et al. (2003b, K_{03}) and L. J. Kewley et al. (2001, K_{01}) applied to emission-line fluxes from the MPA-JHU DR8 Catalog (G. Kauffmann et al. 2003a; J. Brinchmann et al. 2004; C. A. Tremonti et al. 2004). Only spectra with SNRs greater than 5 in the relevant narrow lines are classified with the BPT diagram. We also use the three-band AGN color cut from T. H. Jarrett et al. (2011) to identify MIR AGNs in the sample. The general properties of our Primary Keck AO sample are listed in Table 1.

The Primary Keck AO Merger Sample consists of local galaxies, with a median redshift of 0.098 (corresponding to $1'' = 1.813$ kpc). In Figure 2, we show the optical narrowline ratios of the sample on the BPT diagram. Of the 46 targets, 29 lie in the AGN region, 14 in the composite region, and 2 in the SF region; one target is excluded, due to having $\text{SNR} < 5$ in at least one required emission line. In Figure 3, we show the MIR colors of the sample ($W_1 - W_2$ versus $W_2 - W_3$), with 19 targets falling within the stringent AGN wedge defined by T. H. Jarrett et al. (2011).

In both Figures 2 and 3, we include the optical line ratios and MIR colors of the general population of highly disturbed Galaxy Zoo mergers ($f_m > 0.4$; D. W. Darg et al. 2010) as background contours. These figures serve two purposes. First, they demonstrate that the SDSS/WISE offset-selected sample occupies a distinct region of optical and MIR diagnostic space compared to the general merger population, as expected given the MIR AGN preselection. Specifically, 93.5% of the target sample lies in the AGN or composite regions of the BPT diagram, compared to 58.8% of the general merger population, and 41% of the targets fall within the MIR AGN wedge compared to only 1.92% of all Galaxy Zoo mergers. Second, these figures establish the diagnostic context for interpreting the substructure results presented in Section 4, where we examine how the incidence and properties of resolved NIR substructure depend on optical and MIR classification.

We additionally show the distribution of color excess, $E(B - V)$, for the Primary Keck AO Merger Sample in Figure 4,

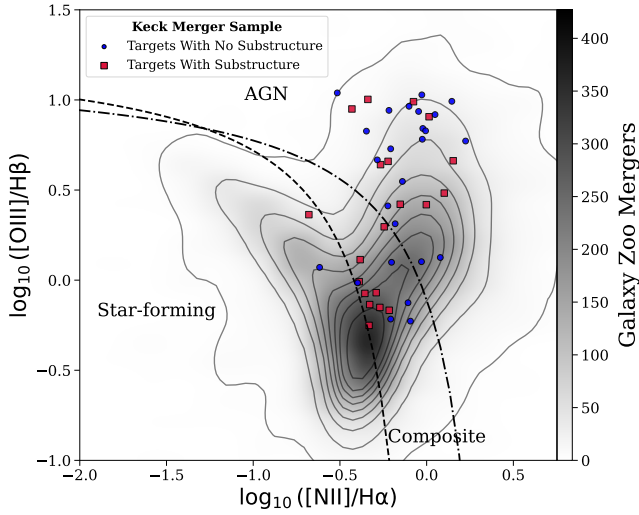


Figure 2. BPT diagram for the Primary Keck AO Merger Sample (46 systems with SDSS/WISE offsets <1.5), shown relative to the general population of highly disturbed Galaxy Zoo mergers ($f_m > 0.4$; shaded contours). Narrow emission-line ratios are drawn from the MPA-JHU DR8 catalog (G. Kauffmann et al. 2003a; J. Brinchmann et al. 2004; C. A. Tremonti et al. 2004). The crimson squares denote systems for which Keck AO imaging reveals previously unresolved NIR substructure, while the blue points indicate systems with no detected substructure. The empirical SF demarcation from G. Kauffmann et al. (2003b) (dashed line) and the theoretical maximum starburst boundary from L. J. Kewley et al. (2001) (dashed-dotted line) are shown for reference; galaxies between these curves are classified as composite systems. This figure demonstrates that the SDSS/WISE offset-selected sample is preferentially composed of AGN and composite classifications compared to the general merger population, as expected given the MIR AGN selection. The substructure classifications are shown here to provide diagnostic context for the sample and to illustrate where systems with and without detected substructure reside in optical emission-line parameter space. The definition of substructure and its relationship to the SDSS/WISE offsets are presented in Section 4.1. One target (J033037) is excluded due to insufficient SNR (<5) in the required emission lines.

separating systems with and without detected substructure (see Section 4). This figure is included to assess whether the success of the SDSS/WISE offset method is driven primarily by extinction effects, and to demonstrate that substructure is identified across a broad range of obscuration rather than only in the most highly reddened systems.

A crossmatch with the Big Multi-AGN Catalog (the Big MAC; R. W. Pfeifle et al. 2025) reveals that the 46 targets in the Primary Keck AO Merger Sample (SDSS/WISE offsets <1.5) include 13 previously identified candidate dual AGNs and 2 confirmed dual AGNs. However, only one of the confirmed systems has a nuclear separation small enough to plausibly correspond to the SDSS/WISE offset measured here; the second confirmed system has a much larger separation and is unlikely to drive the observed offset. Candidate or confirmed dual AGNs with very large separations are typically resolved galaxy pairs in which the SDSS/WISE offset traces substructure within one of the merging galaxies rather than the separation between the two galaxies themselves. Such systems may potentially host more than two accreting nuclei.

Throughout this work, we distinguish between systems for which Keck AO imaging reveals previously unresolved NIR substructure and those for which no such substructure is detected. These classifications are shown throughout the figures in this section, to provide context for the physical and diagnostic properties of the sample. The identification and quantitative definition of substructure is presented in

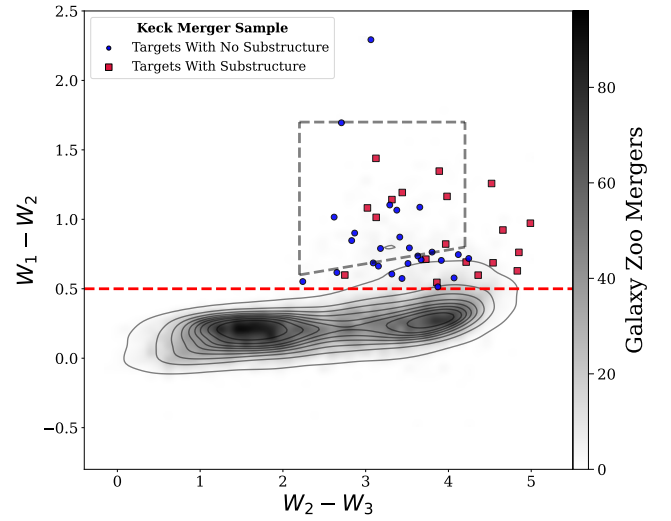


Figure 3. WISE MIR color-color diagram ($W_1 - W_2$ versus $W_2 - W_3$) for the 46 targets in the Primary Keck AO Merger Sample, shown relative to the parent population of highly disturbed Galaxy Zoo mergers ($f_m > 0.4$; shaded contours). The blue circles denote targets without detected NIR substructure, while the crimson squares indicate targets for which substructure is identified in Keck AO imaging (see Section 4.1). The red dotted horizontal line shows the MIR-color-selection criterion ($W_1 - W_2 > 0.5$) used to construct the sample, which preferentially selects systems likely to host accreting SMBHs (L. Blecha et al. 2018). The dashed gray box outlines the stringent MIR AGN selection wedge defined by T. H. Jarrett et al. (2011). This figure serves two purposes. First, it demonstrates that the SDSS/WISE offset-selected sample occupies a distinct region of MIR diagnostic space compared to the general merger population, consistent with the MIR AGN preselection criteria. Second, by identifying which targets contain resolved NIR substructure, this figure provides the MIR classification context needed to interpret the substructure detection rates presented in Section 4.1, enabling assessment of how substructure incidence depends on MIR AGN diagnostics. One target (J152659) is not included due to the absence of a reliable W_3 measurement.

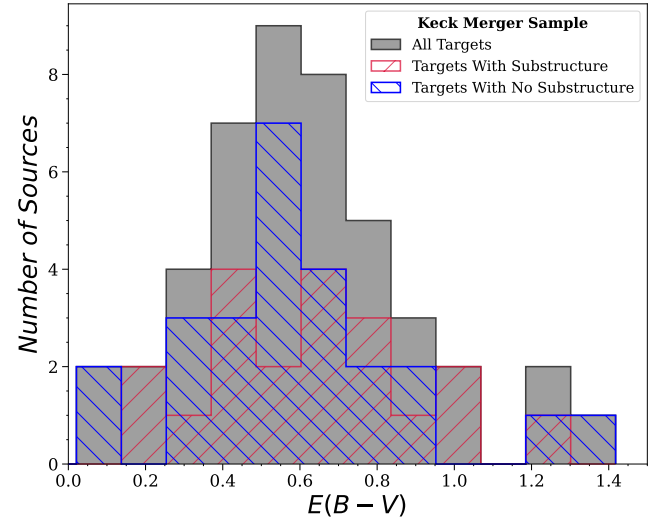


Figure 4. Distribution of optical extinction, parameterized by the color excess $E(B - V)$, for the Primary Keck AO Merger Sample. Extinction values are drawn from the MPA-JHU DR8 Catalog (G. Kauffmann et al. 2003a; J. Brinchmann et al. 2004; C. A. Tremonti et al. 2004). The gray histogram shows the full sample, while the blue hatched bins and crimson hatched bins indicate systems without and with detected NIR substructure in the Keck AO imaging, respectively (see Section 4.1). This figure characterizes the extinction properties of the offset-selected merger sample and shows where systems with and without detected substructure reside in extinction space. The implications of these distributions for substructure detection and their relationship to SDSS/WISE positional offsets are discussed in Section 4.1.

Section 4.1, where we assess whether the detected substructure spatially corresponds to the SDSS/WISE positional offsets and evaluate the effectiveness of the offset selection method. Here, the substructure classifications are shown for reference only, to illustrate how the targets populate optical and MIR diagnostic space prior to the detailed structural analysis.

2.2. Expanded-offset Sample and UKIDSS Imaging

The Primary Keck AO Merger Sample described in Section 2.1 is restricted to SDSS/WISE offsets $<1.5''$ corresponding to projected separations $\lesssim 1$ kpc. Although this regime is the primary focus of this work, it is important to validate this selection technique by exploring its reliability in tracing substructure across broader angular separations and identifying the limit of its robustness at smaller scales. In addition, the small field of view (FOV) of the NIRC2 images and the absence of reference stars from most Keck frames prevent direct absolute astrometric registration of the Keck images to the SDSS and WISE coordinate systems (Wide Camera FOV: $40'' \times 40''$; Narrow Camera FOV: $10'' \times 10''$). As a result, while the Keck imaging reveals substructure, it is not possible to directly verify whether the detected components correspond spatially to the SDSS or WISE centroids.

To address this limitation and independently test the reliability of the SDSS/WISE offset selection method and explore its dependence on offset size, we constructed an expanded-offset sample extending to larger angular separations of $0.15'' < \text{offset} < 6''$, corresponding to the angular resolution limit of the highest-resolution band (W_1) in WISE. Applying the same Galaxy Zoo merger classification ($f_m > 0.4$), MIR color selection ($W_1 - W_2 > 0.5$), and magnitude cut ($W_1 < 15$) described in Section 2.1, this expanded selection yields 540 merger systems.

We then identified 61 merger systems within this expanded-offset sample with publicly available NIR imaging from UKIDSS (A. Lawrence et al. 2007). Unlike the Keck AO data, the UKIDSS images provide reliable World Coordinate System (WCS) solutions, enabling direct comparison between the SDSS and WISE centroids and the NIR emission. Because the angular resolution of UKIDSS ($\sim 0.8''$) is sufficient to resolve sources corresponding to larger SDSS/WISE offsets, these data provide an independent means of verifying whether the positional offsets correspond to physically distinct emission components. An example UKIDSS image with SDSS and WISE positions overlaid is shown in Figure 5.

In addition, we identified seven targets within the expanded-offset sample that have Keck AO imaging, which are included in the Expanded Keck AO Sample described in Table 2. Together, the UKIDSS and expanded Keck samples enable validation of the offset selection method across a broader range of angular separations and provide an independent check on whether SDSS/WISE offsets trace physically distinct NIR emission components.

2.3. Comparison Samples

To evaluate whether the SDSS/WISE offset selection and merger classification independently contribute to the detection of substructure, we constructed two comparison samples drawn from the same Galaxy Zoo–CatWISE2020 parent population.

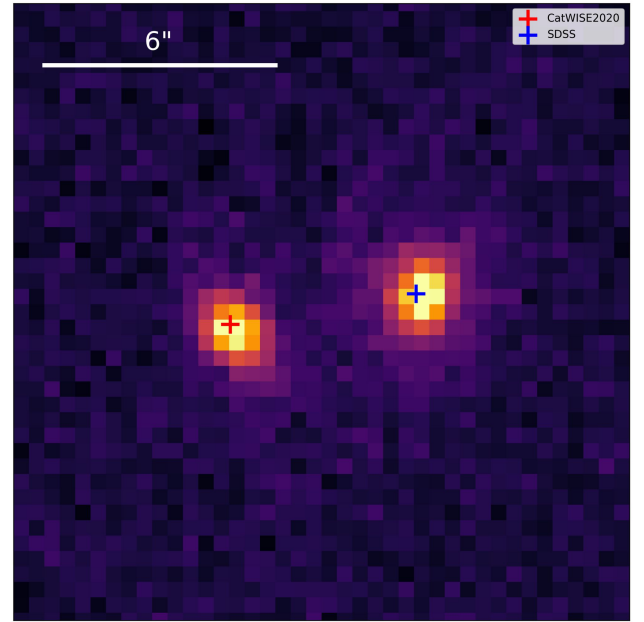


Figure 5. Example UKIDSS K -band image of J131012.68+001809.3 from the UKIDSS Merger Sample. The UKIDSS imaging provides accurate absolute astrometry, enabling the direct overlay of the SDSS (blue cross) and WISE (red cross) centroid positions. The $4.914''$ offset between these centroids corresponds to distinct NIR emission components, separated by $4.961''$, resolved by UKIDSS but unresolved by WISE. This figure demonstrates that SDSS/WISE astrometric offsets trace physically distinct merger-driven substructure.

2.3.1. Nonmerger Comparison Sample

First, we constructed a sample of galaxies with significant SDSS/WISE offsets that are not classified as mergers. This sample was generated using the same selection criteria described in Section 2.1, except that we required a low merger vote fraction ($f_m < 0.4$). This selection yields 5815 nonmerger galaxies with red MIR colors, reliable CatWISE detections, and significant SDSS/WISE offsets corresponding to projected separations $\lesssim 1$ kpc.

From this sample, we identified 40 systems with archival Keck AO imaging, forming the Keck Nonmerger Comparison Sample. This sample allows us to assess whether SDSS/WISE offsets alone, independent of merger status, are sufficient to produce detectable substructure.

We compare the optical emission-line classifications, MIR colors, and optical extinctions of this sample with those of the Primary Keck AO Merger Sample in Figures 6, 7, and 8, respectively. These figures, which are analogous to Figures 2, 3, and 4, allow direct comparisons of the BPT classifications, WISE colors, and optical extinction distributions of offset-selected galaxies with and without merger signatures. This comparison shows that the Keck Nonmerger Comparison Sample spans a similar range of AGN and composite classifications, MIR colors, and optical extinctions as the Primary Keck AO Merger Sample, indicating that the two samples have comparable optical and MIR properties, despite their different merger classifications.

To verify that the Keck Nonmerger Comparison Sample is well matched to the Primary Keck AO Merger Sample, we statistically compare the distributions of the SDSS/WISE offset, redshift, $W_1 - W_2$, W_1 magnitude, optical extinction, BPT classification, and Jarrett AGN classification. A two-

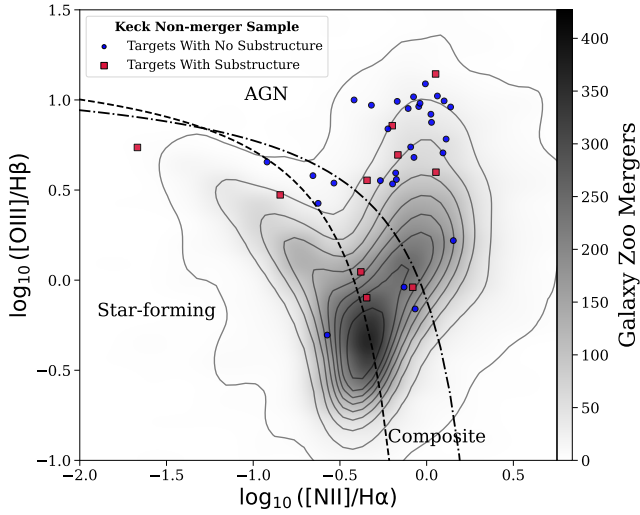


Figure 6. BPT diagram for the Keck Nonmerger Comparison Sample (40 galaxies with SDSS/WISE offsets but no merger classification, $f_m < 0.4$), shown relative to the general population of Galaxy Zoo mergers ($f_m > 0.4$; shaded contours). The crimson squares denote systems for which Keck AO imaging reveals NIR substructure, while the blue points indicate systems with no detected substructure. The empirical SF demarcation from G. Kauffmann et al. (2003b) (dashed line) and the theoretical maximum starburst boundary from L. J. Kewley et al. (2001) (dashed-dotted line) are shown for reference. This figure demonstrates that the Keck Nonmerger Comparison Sample spans a similar range of optical spectroscopic classifications as the Primary Keck AO Merger Sample, allowing us to assess whether SDSS/WISE offsets alone, independent of merger status, are associated with unresolved NIR substructure.

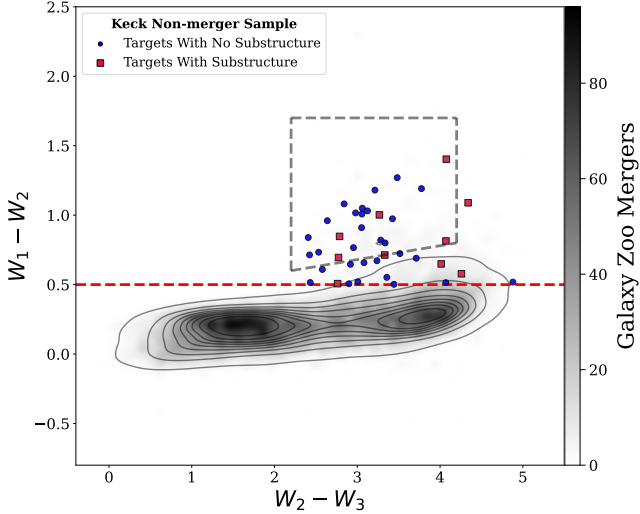


Figure 7. WISE color-color diagram for the Keck Nonmerger Comparison Sample, shown relative to the parent Galaxy Zoo merger population ($f_m > 0.4$; shaded contours). The crimson squares denote systems with detected NIR substructure, and the blue points indicate systems without detected substructure. The horizontal dashed line marks the $W_1 - W_2 > 0.5$ AGN color selection threshold (L. Blecha et al. 2018), and the dashed box indicates the AGN selection wedge from T. H. Jarrett et al. (2011). This figure shows that the Keck Nonmerger Comparison Sample occupies a similar region of MIR color space as the Primary Keck AO Merger Sample, enabling a direct test of whether SDSS/WISE positional offsets alone can identify systems with unresolved NIR substructure.

sample Kolmogorov–Smirnov (KS) test indicates no statistically significant difference between the two samples ($p > 0.05$; see Appendix A1 for the distributions and specific values) in the SDSS/WISE offset, redshift, $W_1 - W_2$, W_1

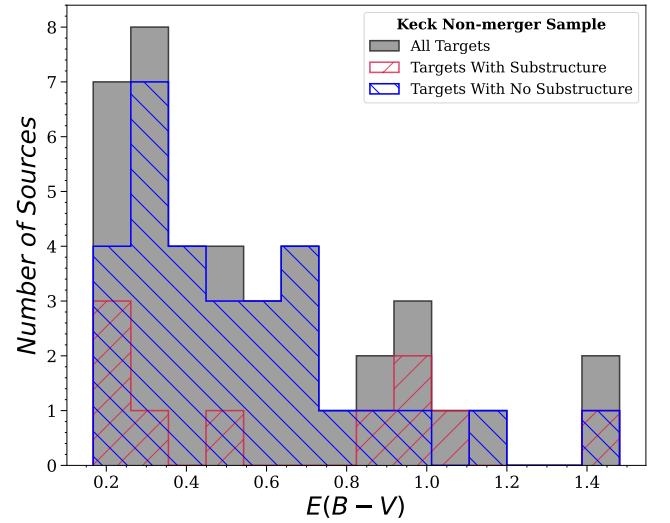


Figure 8. Distribution of optical extinction, parameterized by the color excess $E(B - V)$, for the Keck Nonmerger Comparison Sample. Extinction values are drawn from the MPA-JHU DR8 Catalog (G. Kauffmann et al. 2003a; J. Brinchmann et al. 2004; C. A. Tremonti et al. 2004). The gray histogram shows the full sample, while the blue hatched bins and crimson hatched bins indicate systems without and with detected NIR substructure in archival Keck AO imaging, respectively (see Section 4.1). This figure provides a direct comparison to the Primary Keck AO Merger Sample by characterizing the extinction properties of nonmergers with SDSS/WISE positional offsets. The implications for substructure detection and the role of astrometric offsets are discussed in Section 4.1.

magnitude, and optical extinction. To further compare the optical and MIR properties of the samples, we conduct a chi-square test on the BPT classifications and Fisher’s exact test on the fraction of Jarrett AGNs in each sample. We find no statistically significant difference in the distribution of the BPT classifications (AGN, composite, and SF; $\chi^2(2) = 2.033$, $p = 0.362$) and Jarrett AGN classifications ($p = 0.281$) for these two samples. These statistical comparisons demonstrate that the Keck Nonmerger Comparison Sample is well matched to the Primary Keck AO Merger Sample in its optical and MIR properties, ensuring that differences in the substructure detection fraction cannot be attributed to systematic differences in the underlying sample properties or selection criteria.

2.3.2. Nonoffset Merger Comparison Sample

Second, we constructed a comparison sample of mergers that satisfy all selection criteria, except for the SDSS/WISE offset requirement. Applying the Galaxy Zoo merger classification, MIR color selection, and magnitude cut, but requiring SDSS/WISE offsets $< 0''.15$, yields 50 merger systems with no statistically significant SDSS/WISE offset.

Of these, 11 systems have archival Keck AO imaging and form the Keck Nonoffset Comparison Sample. This sample enables us to test whether substructure detection is specifically associated with SDSS/WISE positional offsets, rather than being a generic property of late-stage mergers.

Together, these comparison samples provide independent tests of the relative roles of merger status and astrometric offsets in identifying unresolved NIR substructure. A summary of all samples and their hierarchical relationships is provided in Table 2.

3. Observations and Data Reduction

3.1. Keck AO Observations

We observed a total of 40 targets (36 targets from the Primary Keck AO Merger Sample and 4 additional targets from the Expanded Keck AO Sample) using the Keck II Telescope and the NIRC2 NIR camera (PI: K. Matthews; P. Wizinowich et al. 2000; M. A. van Dam et al. 2006; P. L. Wizinowich et al. 2006). Observations were conducted over three nights between UT 2021 September 19 and UT 2022 March 19, using Laser Guide Star and Natural Guide Star Adaptive Optics (LGSAO and NGS AO, respectively).

Images were obtained in the K_p filter ($\lambda_c = 2.124 \mu\text{m}$, $\Delta\lambda = 0.351 \mu\text{m}$). Most targets were observed with the Narrow Camera (FOV: $10'' \times 10''$; pixel scale: $0.009942 \text{ pixel}^{-1}$), while eight targets were observed with the Wide Camera (FOV: $40'' \times 40''$; pixel scale: $0.039686 \text{ pixel}^{-1}$). The total exposure times ranged from 900 s to 1620 s per target under photometric conditions with natural seeing between $0.5''$ and $1.0''$ (see Appendix B).

A three-point dither pattern was used for all observations. Tip-tilt stars were observed contemporaneously with each science target to monitor AO performance and characterize the instantaneous PSF. The average PSF FWHM was $0.07''$ for the Narrow Camera and $0.13''$ for the Wide Camera. Flat fields, dark frames, and photometric standard stars were obtained for calibration.

3.2. Data Reduction

The data reduction followed standard NIRC2 procedures, including dark subtraction, flat-field correction, bad-pixel masking, sky subtraction, and geometric distortion correction using the most recent distortion solution (M. Service et al. 2016). Individual dithered frames were aligned using the centroid of the brightest nuclear component and median-combined to produce the final science images. Flux calibration was performed using standard stars observed on the same nights.

3.3. Identification of Compact Sources and Aperture Photometry

Because the targets are advanced mergers with disturbed morphologies, strong tidal features, and diffuse stellar emission, conventional two-dimensional surface-brightness-profile fitting using Sérsic or PSF-decomposition techniques was not feasible. The limited NIRC2 FOV further prevented robust modeling of the extended host galaxy light.

Instead, we identified compact emission sources visually in the AO images and measured their photometric properties using aperture photometry, following the established techniques used in imaging studies of merging galaxies and as described below (e.g., M. Trancoso et al. 2025). This approach is well suited for identifying compact, unresolved nuclear components in crowded or morphologically complex systems.

To minimize cross-contamination between closely separated sources, we adopted a small circular aperture with radius equal to 1.25 times the FWHM of the PSF, as measured from the tip-tilt star observed contemporaneously with each science target. Larger apertures were tested but resulted in significant blending between nearby sources in several systems (e.g.,

the two southwest sources in J150517; see Figure C18), preventing reliable isolation of individual components.

Because this aperture does not enclose the full PSF, aperture corrections were applied using a curve-of-growth analysis derived from the corresponding tip-tilt star. The tip-tilt star provides an empirical measurement of the instantaneous AO PSF, including both the diffraction-limited core and extended halo. For each observation, we measured the fraction of flux enclosed within the adopted aperture radius and applied the corresponding correction factor to estimate the total flux of each compact source.

This method provides a uniform methodology for obtaining total flux estimates for compact, unresolved sources in the sample, while avoiding aperture overlap between neighboring components. However, because of the complex morphologies of merging systems, overlapping stellar emission or diffuse light from foreground substructure may contribute to the measured flux in some cases. Therefore, the fluxes and flux ratios reported here should be interpreted as approximate indicators of the relative prominences of compact nuclear components rather than precise measurements of stellar mass.

To quantify the incidence of substructure, we define a substructure detection as the presence of a secondary source of emission in the Keck AO imaging that is distinct from the primary nuclear component, unresolved in SDSS imaging, and exceeds a flux ratio threshold of $f_{\text{secondary}}/f_{\text{primary}} > 0.1$. We adopt this conservative threshold from the similar criterion of M. J. Koss et al. (2018). To assess whether the Keck observations are sensitive enough to reliably detect secondary sources at the adopted flux ratio threshold, we estimate the minimum detectable flux ratio for each image as the 5σ background noise relative to the primary nucleus flux. We find that a flux ratio of 0.1 is detectable in all Keck AO images across all samples, with the least sensitive image reaching a minimum detectable flux ratio of 0.0515, well below the adopted threshold. We therefore consider all Keck AO samples presented in this work to be complete to the adopted flux ratio threshold of $f_{\text{secondary}}/f_{\text{primary}} > 0.1$.

Following standard practice in IR studies of galaxy mergers, we use the K -band flux ratio as an approximate proxy for the stellar mass ratio, adopting the conventional threshold of 4:1 (flux ratio > 0.25) to distinguish between major and minor mergers (e.g., A. Toomre & J. Toomre 1972; H. M. Hernández-Toledo et al. 2005; C. J. Conselice 2006; M. Trancoso et al. 2025). This major-merger classification is applied only to systems with clearly resolved compact nuclei and is intended to provide an empirical basis for comparison with previous studies, but should not be interpreted as a precise stellar mass measurement. We note that the flux ratios of the major mergers are consistent with those obtained by applying a human-guided aperture selection, as was done in the study by M. Trancoso et al. (2025).

3.4. Archival NIRC2 Imaging

In addition to our observations, we identified 13 targets with publicly available NIRC2 imaging. These archival data were precalibrated using standard procedures including dark subtraction, flat-field correction, bad-pixel masking, and geometric distortion correction. We aligned and combined the archival frames following the same procedures described above.

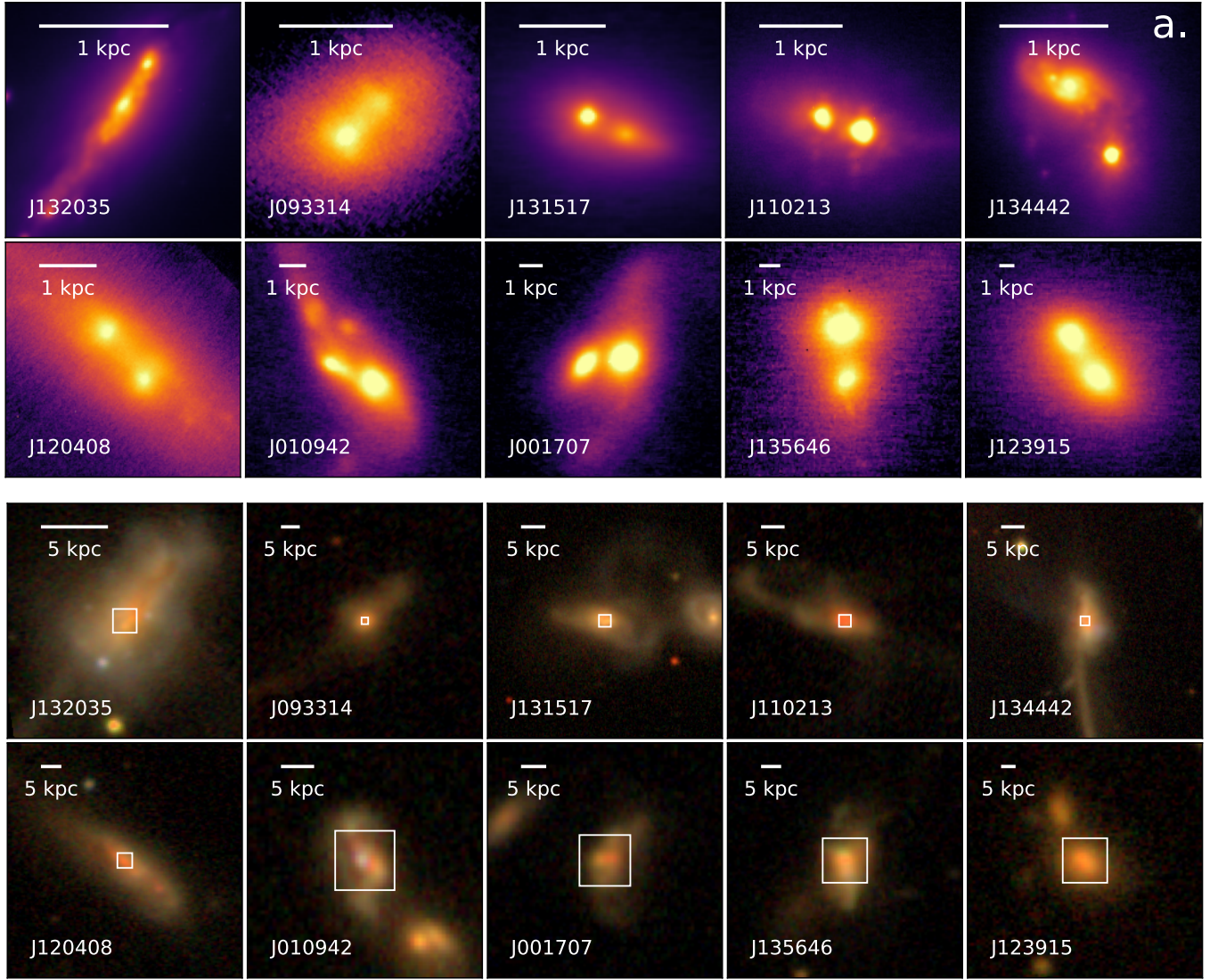


Figure 9. (a). Keck/NIRC2 and SDSS cutout images of the Primary Keck AO Merger Sample. The systems are divided into four subfigures according to their observed NIR morphology: (a) systems with two compact nuclei (i.e. apparent dual-nucleus systems); (b) systems that contain compact secondary sources whose morphologies are consistent with SF regions rather than distinct nuclear components; (c) systems with morphological features consistent with spiral arms or tidal tails; and (d) single-nucleus systems. In each subfigure the top panel shows the Keck/NIRC2 AO K_p -band cutout images and the bottom panel shows the corresponding SDSS gri color cutout images of the same targets. The white squares indicate the FOVs of the Keck/NIRC2 images. Images are oriented with north up and east to the left. Systems in panels (a) and (b) are arranged in order of increasing projected nuclear separation, while systems in panels (c) and (d) are arranged in order of increasing redshift. Although J124136 exhibits apparent substructure, it does not satisfy our adopted flux-ratio threshold and is therefore not classified as a substructure detection. More detailed descriptions of individual targets are provided in Appendix C.

Because flux calibration information was not available for all archival observations, we do not report absolute calibrated fluxes for these systems. However, these images provide valuable structural information, and the flux ratios are independent of absolute flux calibration and are included in the substructure analysis presented in Section 4.1.

4. Results

4.1. Identification and Properties of Substructure

In Figures 9(a)–(d), we present the Keck/NIRC2 AO images of the Primary Keck AO Merger Sample, grouped according to their observed NIR morphology, including systems with apparent dual nuclei, compact secondary sources, spiral arms or tidal features, and those dominated by a single compact nucleus (see Appendix C for descriptions of

individual targets). We note that this grouping is visual and qualitative in nature. These high-resolution images reveal intricate nuclear structure that is unresolved in SDSS imaging, with many systems containing two or more compact sources of emission separated by projected distances of $\lesssim 1$ kpc.

As defined in Section 3.3, a substructure detection in our sample requires a secondary source exceeding a flux ratio threshold of $f_{\text{secondary}}/f_{\text{primary}} > 0.1$ relative to the primary central nucleus. We note that this detection criterion is applied independently of the morphological classifications defined above. For example, some of the systems with prominent spiral arms or tidal features contain secondary emission meeting our criteria for substructure (i.e., J091529, J131534, and J134651), while others in the same group do not (J013720 and J122031). For each system with detected substructure, we identify a substructure pair consisting of the primary nucleus

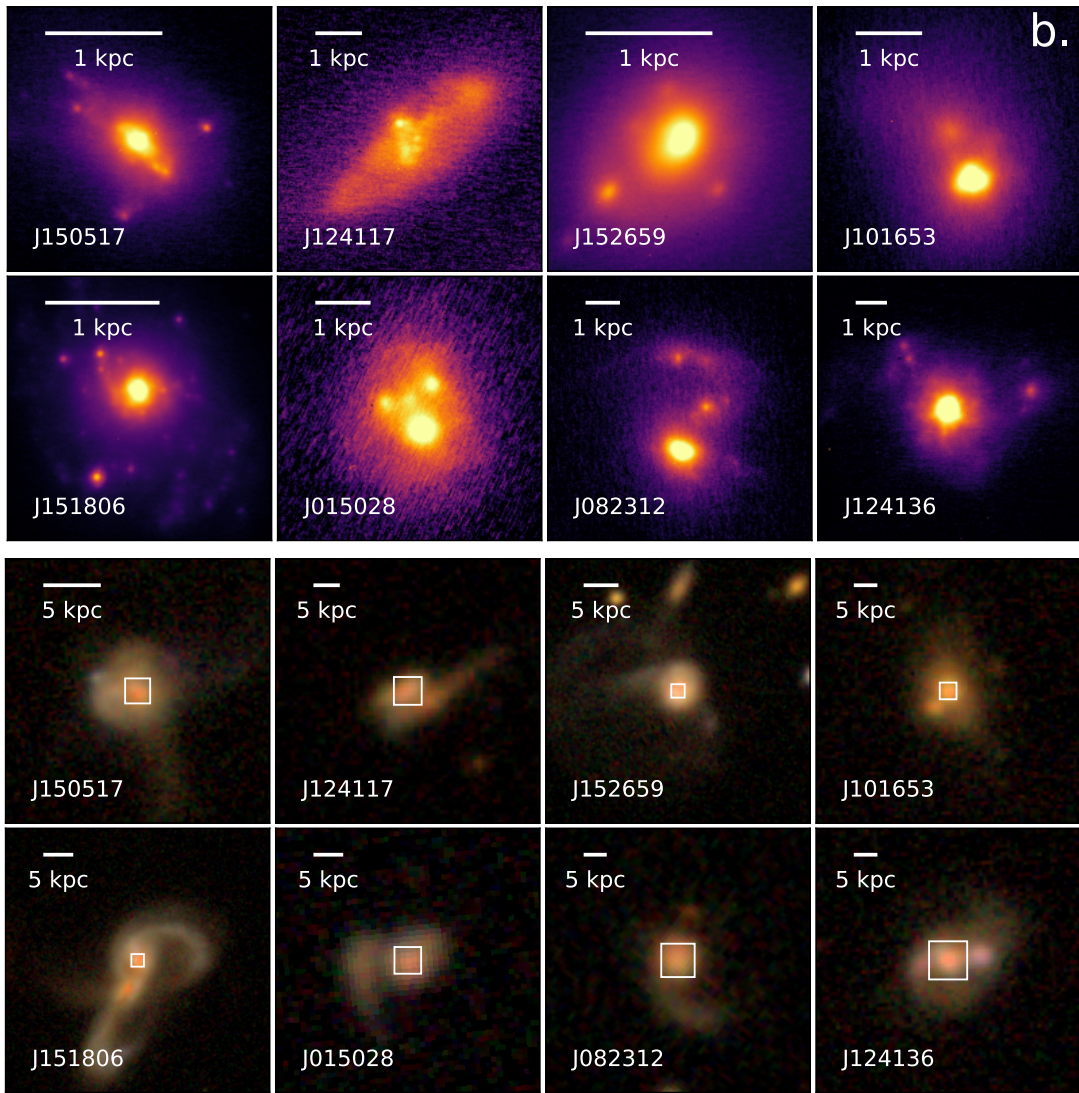


Figure 9. (Continued.)

and the brightest secondary compact source. The selection of eligible secondary sources is guided by the SDSS/WISE positional offset: for systems with offsets $<1''.5$, the offset necessarily corresponds to structure unresolved in SDSS imaging, while systems with larger offsets may include sources that are marginally resolved in SDSS but remain unresolved by WISE.

The photometric measurements, separations, and flux ratios of the substructure pairs are listed in Table 3 (see Section 3.3 for details of the photometric methodology). The detected substructure pairs span angular separations of $0''.19$ – $1''.25$, corresponding to projected physical separations of 176 pc to 3.85 kpc. The distribution of substructure pair separations is shown in Figure 10. This figure illustrates the range of nuclear separations probed by the SDSS/WISE offset selection method and demonstrates that a substantial fraction of the detected substructure corresponds to compact nuclear pairs at subkiloparsec scales.

Of the 46 mergers in the Primary Keck AO Merger Sample, 10 systems exhibit dual compact nuclei separated by <4 kpc with flux ratios greater than 0.25, consistent with the mass ratio criterion for a major merger (approximately 4:1), assuming that the K -band flux traces stellar mass (see

Section 3.3 for details). While detailed surface-brightness modeling is required to obtain precise stellar mass ratios, these flux ratios indicate that many of the detected compact sources are consistent with candidate merging galaxy nuclei.

In some systems, diffuse or asymmetric emission may also contribute to the observed SDSS/WISE positional offset. We emphasize that imaging alone cannot definitively determine whether the detected compact sources correspond to galaxy nuclei, star clusters, or AGNs. Follow-up spectroscopy or multiwavelength observations are required to establish their physical nature.

4.2. Substructure Detection Rates

Our analysis of the reduced and calibrated NIRC2 observations shows that 20 of the 46 systems (43.5%) in the Primary Keck AO Merger Sample (SDSS/WISE offset $<1''.5$) exhibit substructure. Among the systems with detected substructure, 10 are optically classified as AGNs, 9 as composite systems, and 1 as SF, based on their SDSS emission-line classifications (Table 1). Figures 2 and 3 show the locations of these systems in optical emission-line diagnostic space and MIR color space, respectively. Within

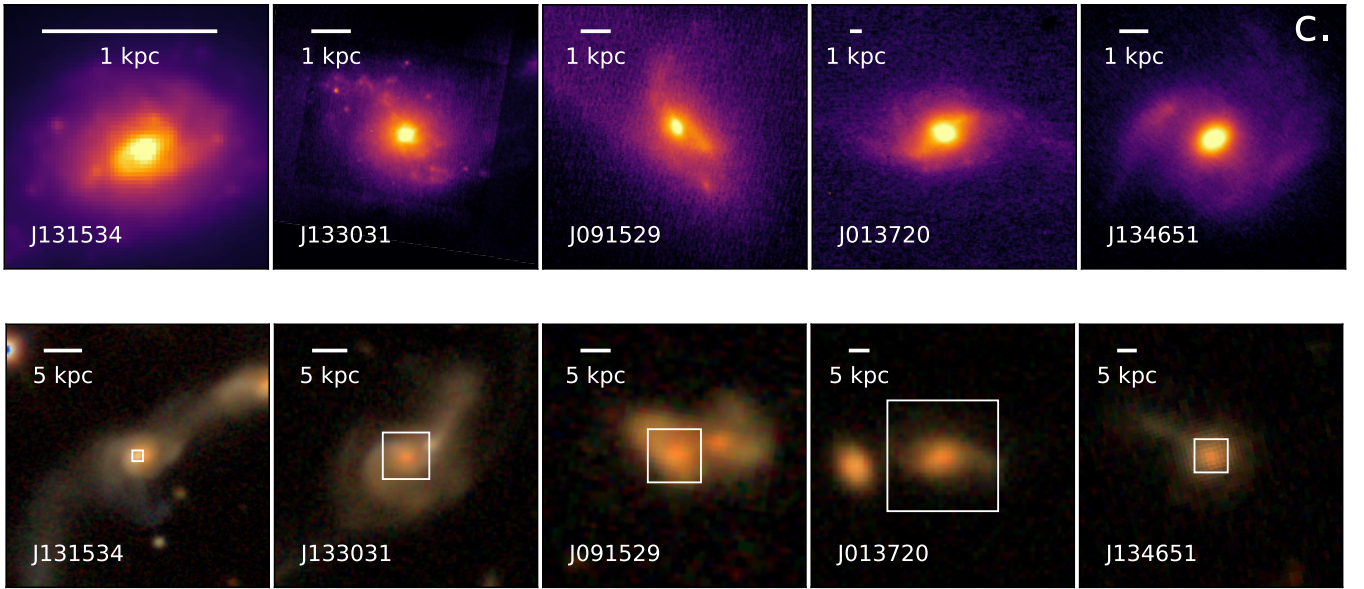


Figure 9. (Continued.)

the Primary Keck AO Merger Sample, substructure is detected in 34% (10/29) of optically classified AGNs, 64% (9/14) of composite systems, and 50% (1/2) of SF galaxies. Using MIR selection criteria, substructure is detected in 42% (8/19) of the Jarrett AGNs. Although the absolute numbers of substructure detections in AGNs and composite systems are similar, there is a higher detection fraction in composite targets.

Substructure detection is also strongly associated with red MIR colors. In particular, 89% (8/9) of systems with $W_2 - W_3 > 4.2$ contain substructure. Figure 4 shows the distribution of optical extinction, parameterized by $E(B - V)$ from the MPA-JHU catalog, for systems with and without detected substructure. Substructure is detected across the full range of extinction values in the sample; however, the detection fraction increases from 36% at lower extinction to 52% for systems with $E(B - V) > 0.6$, indicating that highly obscured systems are particularly likely to host unresolved nuclear substructure.

To investigate how the detection rate depends on offset size, we also analyzed the Expanded Keck AO Merger Sample, which includes mergers with SDSS/WISE offsets extending to $6''$. Combining this sample with the UKIDSS Merger Sample, we identify substructure in an additional 51 systems. Across the full set of mergers with Keck AO and UKIDSS imaging, substructure is detected in 71 of 114 systems, corresponding to an overall detection rate of 62%. This higher detection rate reflects the inclusion of systems with larger offsets, for which the separation between nuclear components is more readily resolved.

4.3. Robustness of the SDSS/WISE Offset Method across Offset Magnitudes

A key question is whether the SDSS/WISE offset selection method remains reliable at the smallest offsets considered in this work, where astrometric uncertainties could potentially dominate over true physical separations. If the observed offsets were primarily driven by astrometric noise rather than genuine substructure, the success rate of detecting substructure in high-

resolution imaging would be expected to decrease systematically toward smaller SDSS/WISE offsets.

To assess whether the SDSS/WISE offset method remains reliable across the full offset range, we measured the substructure detection rate as a function of SDSS/WISE offset using the combined sample of mergers with high-resolution NIR imaging, including the Primary Keck AO Merger Sample ($0.15 < \text{offset} < 1.5''$), the additional mergers in the Expanded Keck AO Merger Sample, and the UKIDSS Merger Sample (Section 2.3). These samples together span the full offset range of $0.15 < \text{offset} < 6''$ and provide a uniform test of the method across both subkiloparsec and larger projected separations.

We find no dependence on the substructure detection rate as a function of offset over the full range of offsets. In Figure 11, we show the substructure detection rate computed in eight bins spanning the subarcsecond range of offsets. In each bin, the detection rate is defined as the fraction of targets in which high-resolution imaging reveals nuclear substructure relative to the total number of targets in that offset interval. The error bars correspond to binomial statistics and represent the 90% confidence interval (CI).

We find no statistically significant decline in the detection rate toward smaller offsets. Instead, the detection rate remains approximately constant across the full range of SDSS/WISE offsets probed, including the smallest offsets, where astrometric uncertainties would be expected to have the greatest impact.

This result suggests that the effectiveness of the SDSS/WISE offset selection method does not degrade at small offsets and may suggest that the observed offsets are driven by genuine unresolved nuclear substructure rather than random astrometric errors. We emphasize, however, that this analysis is not conclusive, as a robust assessment of the contribution of astrometric uncertainties would require a comparison to simulations or mock catalogs. Nevertheless, the SDSS/WISE offset method remains reliable for identifying subkiloparsec nuclear pairs across the full offset range considered in this work.

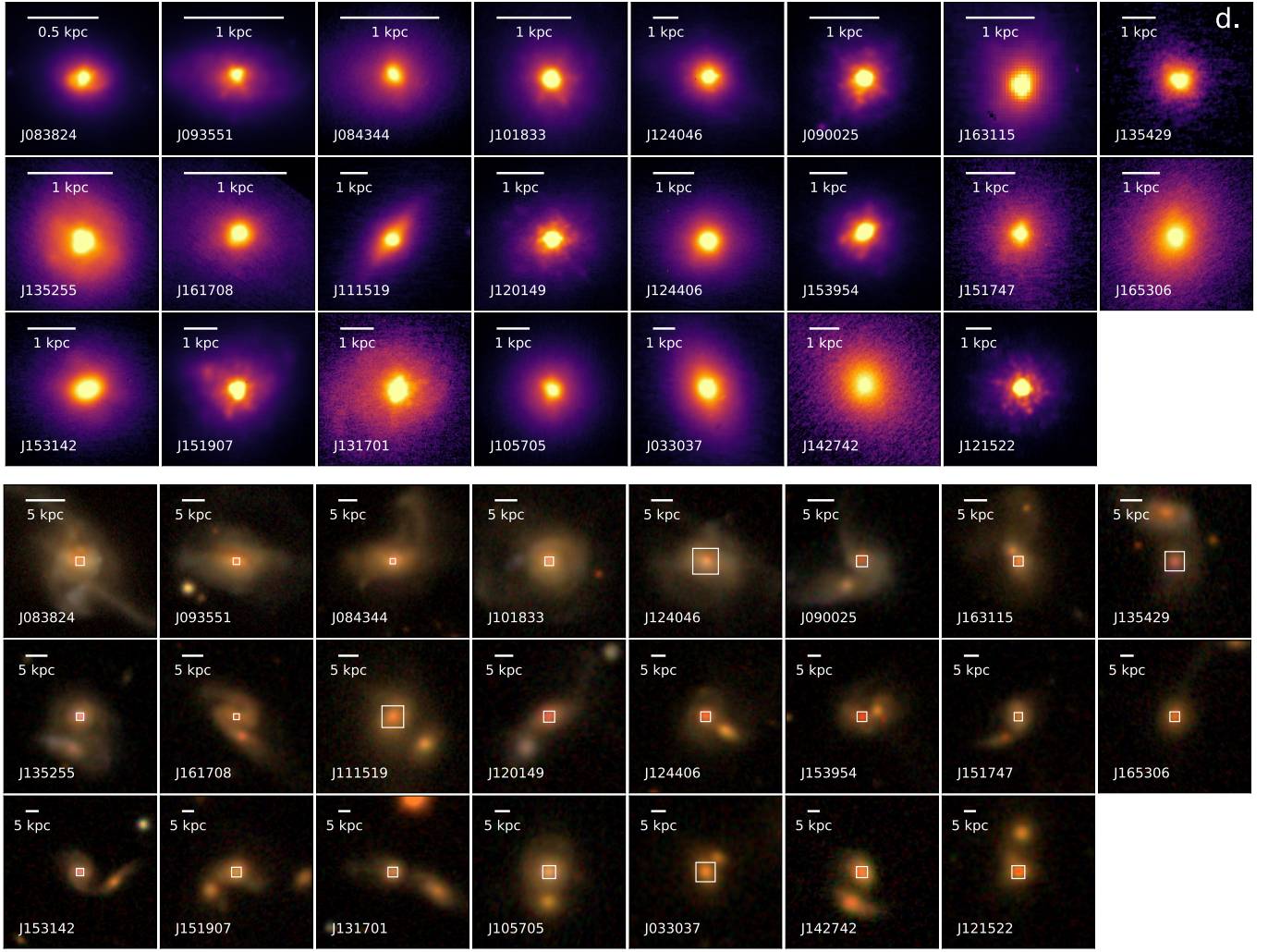


Figure 9. (Continued.)

4.4. Geometric Relationship between SDSS/WISE Offsets and Nuclear Substructure

A key test of the SDSS/WISE offset selection method is whether the measured positional offsets trace the geometry of the underlying nuclear substructure identified in high-resolution NIR imaging. If the SDSS and WISE centroids are displaced due to unresolved multiple sources of emission, the magnitude and orientation of the SDSS/WISE offset should correlate with the separation and position angle (PA) of the substructure pair.

Directly overlaying the SDSS and WISE coordinates on the Keck NIRC2 images is not possible, because the NIRC2 images lack absolute astrometric registration. Instead, we test whether the relative geometry of the SDSS/WISE offsets is statistically correlated with the geometry of the substructure identified in the imaging.

This analysis was conducted on the 71 targets with detected substructure drawn from the combined sample of mergers with high-resolution NIR imaging, including the Primary Keck AO Merger Sample, the additional systems in the Expanded Keck AO Merger Sample, and the UKIDSS Merger Sample, spanning SDSS/WISE offsets of $0''.15 < \text{offset} < 6''$. For each target, we identified a substructure pair, as defined in Section 4.1, and measured its angular separation and PA.

For the Keck AO imaging, the lack of absolute astrometric registration prevents identifying which component corresponds directly to the SDSS or WISE centroid. To account for this ambiguity, we computed the SDSS/WISE offset PA in both possible directions and adopted the value that minimized the difference relative to the substructure pair PA. For the UKIDSS imaging, which has accurate absolute astrometry, we defined the substructure pair as the sources nearest to the SDSS and WISE coordinates, respectively.

Figure 12 compares the SDSS/WISE positional offsets to the measured substructure separations and PAs. We find strong correlations between the offset magnitude and substructure separation (Spearman rank correlation: $\rho = 0.864$, $p \sim 0$) and between the offset PA and substructure PA (Spearman rank correlation: $\rho = 0.871$, $p \sim 0$).

The strong correlation in PA demonstrates that the SDSS/WISE offsets reliably trace the orientation of the underlying nuclear substructure. The offset magnitudes are systematically smaller than the substructure separations, as expected, because the measured centroid shift depends on the relative brightness of the emission components. When both sources contribute significantly to the MIR emission, the WISE centroids are displaced toward the flux-weighted midpoint between them. A similar effect occurs for the SDSS centroid in systems with

Table 3
Photometric Measurements of Nuclear Substructure Pairs in the Primary Keck AO Merger Sample

Photometric Properties of Substructure Pairs in the Primary Keck AO Merger Sample						
(1) Target	(2) Offset (arcsec)	(3) Separation (arcsec)	(4) Separation (kpc)	(5) Kp Flux (mJy)	(6) Flux Ratio ^a ($f_{\text{primary}}/f_{\text{secondary}}$)	(7) Morph.
J001707.95+011506.3	...	...	...	5.630 $\pm$ 1.591	...	1
J010942.21−004417.4	0.511	0.986	1.910	1.826 $\pm$ 0.516	3.083	1
J015028.40+130858.4	0.443	1.129	1.871	0.076 $\pm$ 0.001	...	1
J082312.61+275139.8	0.275	0.329	0.843	0.052 $\pm$ 0.0004	1.474	2
J091529.62+090601.5	0.294	0.564	1.617	0.118 $\pm$ 0.052	...	2
J093314.80+630945.0	0.431	0.917	2.300	0.052 $\pm$ 0.025	...	3
J101653.82+002857.0	0.167	0.190	0.405	0.115 $\pm$ 0.005	...	1
J110213.01+645924.8	0.275	0.350	0.737	0.014 $\pm$ 0.001	1.323	2
J120408.82+132117.0	0.486	0.740	1.070	0.073 $\pm$ 0.015	...	1
J123915.40+531414.6 ^b	0.306	1.161	3.855	0.982 $\pm$ 0.020	...	1
J124117.64+273252.3	0.411	0.266	0.655	0.573 $\pm$ 0.012	1.713	1
J131517.26+442425.5 ^b	0.689	0.711	0.503	0.063 $\pm$ 0.001	...	1
J131534.00+620728.6 ^b	0.585	0.287	0.177	0.059 $\pm$ 0.001	1.074	1
J132035.40+340821.5 ^b	1.209	0.784	0.365	...	...	1
J134442.16+555313.5 ^b	0.799	1.035	0.767	0.018 $\pm$ 0.0003	1.163	2
J134651.82+371231.0	0.230	0.633	2.209	0.019 $\pm$ 0.0003	...	3
J135646.10+102609.0 ^b	0.258	1.253	2.771	0.318 $\pm$ 0.002	...	1
J150517.88+080912.7	0.194	0.347	0.270	0.041 $\pm$ 0.0003	2.501	2
J151806.13+424445.0	0.500	1.083	0.863	0.309 $\pm$ 0.003	...	2
J152659.44+355837.0	0.376	0.631	0.677	0.079 $\pm$ 0.001	...	2
				0.950 $\pm$ 0.016	...	2
				0.128 $\pm$ 0.002	...	2
				0.531 $\pm$ 0.048	...	2
				0.145 $\pm$ 0.013	...	

Notes. Column (1): target identifier. Column (2): SDSS/WISE positional offset. Columns (3)–(4): angular and physical separation between nuclear components. Column (5): Kp flux density. Column (6): flux ratio. Column (7): NIR morphology as defined in Section 4.1—(0) single nucleus; (1) dual nuclei; (2) compact secondary source consistent with an SF region; and (3) prominent spiral arms or tidal features.

^a Flux ratios are reported only for systems with compact, well-resolved nuclear components and those consistent with major mergers (mass ratio $\lesssim 4$: 1), where aperture-corrected photometry is reliable (Section 3.3). Flux ratios are omitted for systems where photometry may be affected by extended emission, blending, or uncertain aperture corrections.

^b Archival Keck observations lack absolute flux calibration; only separations and flux ratios are reported. This table demonstrates that a subset of SDSS/WISE offset-selected mergers contain compact nuclear pairs with flux ratios consistent with major mergers.

separations smaller than $\sim 1''.5$, where the components remain unresolved.

These results provide direct geometric validation that the SDSS/WISE offsets are physically associated with unresolved nuclear substructure and reliably trace both its orientation and characteristic spatial scale.

4.5. Comparison Sample Results and Validation of Selection Criteria

To isolate the relative roles of merger classification and SDSS/WISE positional offsets in driving substructure detection, we analyzed two comparison samples described in Section 2.3: (i) the Keck Nonmerger Comparison Sample, consisting of galaxies with significant SDSS/WISE offsets but no merger classification; and (ii) the Keck Nonoffset

Comparison Sample, consisting of mergers that satisfy all selection criteria except the SDSS/WISE offset requirement. Throughout this section, detection rates are reported with 95% binomial CIs estimated using the Jeffreys method, and statistical differences are assessed with Fisher’s exact tests.

4.5.1. Keck Nonmerger Comparison Sample

The Keck Nonmerger Comparison Sample consists of 40 galaxies with low merger vote fractions ($f_m < 0.4$), red WISE colors ($W_1 - W_2 > 0.5$), $W_1 < 15$, SDSS/WISE positional offsets in the range $0''.15 < \text{offset} < 1''.5$, and archival NIRC2 imaging. Over the redshift range of the sample, these offsets correspond to projected physical separations $\lesssim 1$ kpc.

Within this sample, 10 of the 40 systems exhibit unresolved NIR substructure detected in Keck AO imaging, corresponding

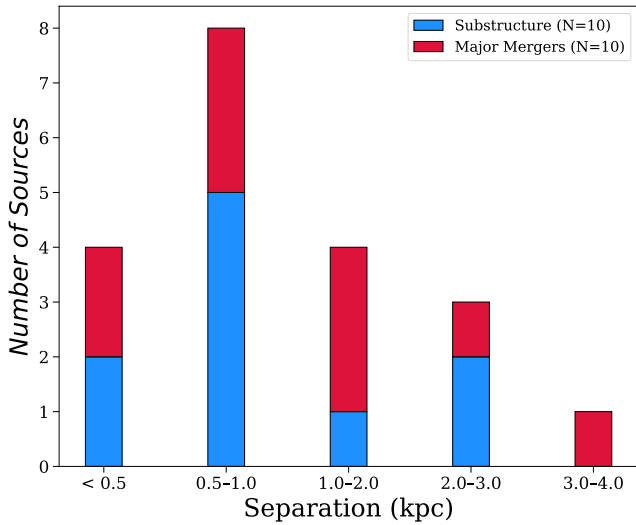


Figure 10. Distribution of nuclear separations for all 20 systems in the Primary Keck AO Merger Sample with detected NIR substructure. The red bars indicate the subset of 10 systems with flux ratios consistent with a major merger ($f_{\text{secondary}}/f_{\text{primary}} > 0.25$; see Section 4.1), while the blue bars correspond to the remaining 10 targets with substructure that do not meet the major-merger criteria. This figure quantifies the spatial scale of the nuclear substructure revealed by Keck AO imaging and demonstrates that the SDSS/WISE offset selection method identifies compact nuclear pairs across a range of separations from ~ 0.2 to ~ 1.25 (176 pc–3.85 kpc), including systems consistent with major mergers.

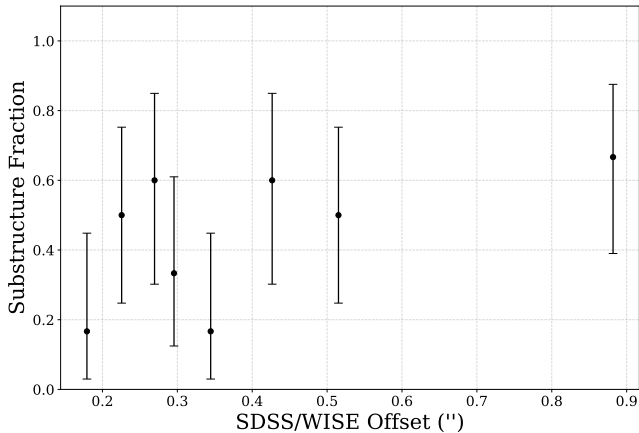


Figure 11. Substructure detection rate as a function of SDSS/WISE positional offset for mergers with high-resolution NIR imaging, including the Primary Keck AO Merger Sample. The sample is divided into eight bins in offset, where the detection rate in each bin is defined as the fraction of systems in which Keck AO imaging reveals unresolved NIR substructure. The error bars represent 90% binomial CIs. This figure evaluates whether the SDSS/WISE offset selection method remains reliable at small offsets, where astrometric noise could potentially dominate. The absence of a systematic decline in detection rate toward smaller offsets may suggest that the observed SDSS/WISE offsets are associated with genuine nuclear substructure rather than being solely driven by astrometric uncertainties.

to a substructure detection rate of 25% (95% CI: 13.6%–39.8%). Of these, 7 systems have nuclear flux ratios > 0.25 , consistent with major mergers under the assumption that the K-band flux traces stellar mass.

Although the detection rate in the Keck nonmerger offset sample is lower than that in the Primary Keck AO Merger sample (43.5%; 95% CI: 29.9%–57.8%), this difference is not statistically significant according to Fisher’s exact test ($p = 0.112$). The absence of a statistically significant

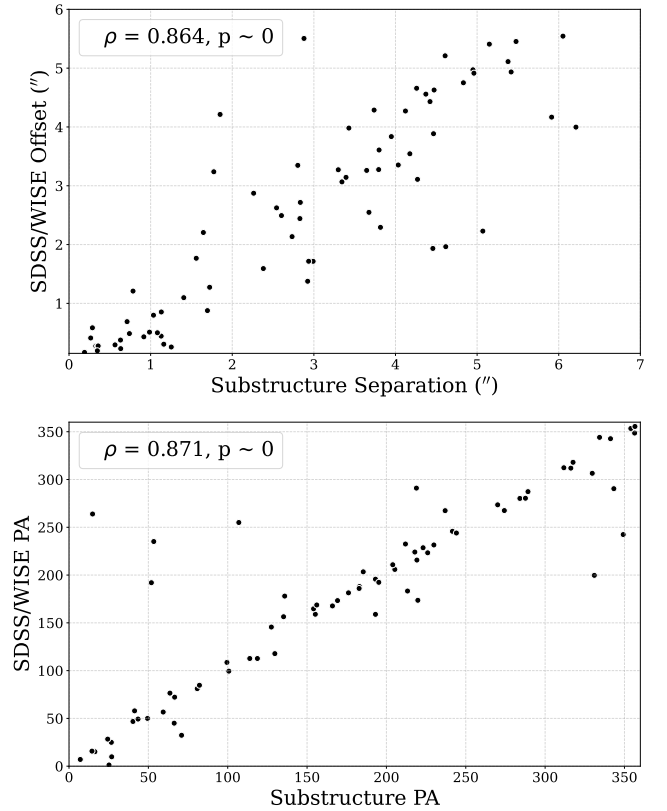


Figure 12. Comparison between the SDSS/WISE offsets and the nuclear substructure geometry for the combined sample of mergers with detected substructure, including the Primary Keck AO Merger Sample, Expanded Keck AO Merger Sample, and UKIDSS Merger Sample. Top: angular separation of the SDSS/WISE positional offset versus the measured separation of the substructure pair. Bottom: PA of the SDSS/WISE positional offset versus the PA of the substructure pair. Spearman rank correlation coefficients (ρ) and corresponding p -values are shown in each panel. The strong correlations demonstrate that the SDSS/WISE positional offsets reliably trace both the orientation and characteristic spatial scale of the underlying nuclear substructure, providing direct geometric validation of the SDSS/WISE offset selection method.

difference in detection rate between these two offset-selected samples suggests that the merger selection step alone does not significantly modify the substructure detection rate. Given that both of these samples are selected to exhibit SDSS/WISE offsets, this result is consistent with the interpretation that the SDSS/WISE offset is more closely associated with higher substructure detection fractions than the merger selection, which appears to play a secondary role.

The detection of substructure, including systems consistent with major mergers, in galaxies not morphologically classified as mergers suggests that the SDSS/WISE offset method is capable of identifying nuclear pairs in systems where merger signatures are not readily apparent in SDSS imaging. This result is consistent with previous studies showing that late-stage mergers can lack clear morphological signatures at optical wavelengths (e.g., M. J. Koss et al. 2018).

4.5.2. Keck Nonoffset Comparison Sample

To further assess whether SDSS/WISE positional offsets are necessary for identifying unresolved substructure, we also examined the Keck Nonoffset Comparison Sample, consisting of 11 merger systems ($f_m > 0.4$) with red WISE colors

($W_1 - W_2 > 0.5$), $W_1 < 15$, archival NIRC2 imaging, and no statistically significant SDSS/WISE positional offset ($< 0''.15$).

Within this sample, only 1 of 11 systems exhibits detectable substructure, corresponding to a detection rate of 9% (95% CI: 1.0%–35.3%). The detected system has a flux ratio of 0.185, below the major-merger threshold.

A comparison of this detection rate to that of the Primary Keck AO Merger Sample shows a statistically significant difference ($p = 0.041$), indicating a significant difference in detection fractions between offset-selected and nonoffset samples. When compared to the Keck Nonmerger Comparison Sample, however, the difference in detection rates is not statistically significant ($p = 0.418$), consistent with a weaker dependence of detection rates on merger selection alone. We note that the Keck Nonoffset Comparison Sample is limited in sample size and statistical power, as reflected by its broad CI, and emphasize that larger samples will be required to further quantify the relative contributions of merger classification and positional offsets to substructure detection.

Taken together with Section 4.5.1, these results suggest that the substructure detection rates do not show a strong dependence on merger selection alone, but rather are more closely related to the presence or absence of SDSS/WISE offsets. This reinforces the interpretation that the SDSS/WISE offsets are strongly associated with the substructure detected in the samples we present. However, we emphasize that the combination of merger classification and SDSS/WISE offset selection yields the highest detection efficiency for unresolved NIR substructure.

4.6. Role of Optical Obscuration in Producing SDSS/WISE Positional Offsets

To investigate the physical origin of the SDSS/WISE positional offsets and assess the role of dust obscuration, we examine archival Hubble Space Telescope (HST) optical imaging for targets in the Primary Keck AO Merger Sample. Of the 46 mergers with SDSS/WISE offsets < 1.5 , 16 have publicly available HST observations obtained with the WFC3 (FOV: $162'' \times 162''$; pixel scale: $0''.04 \text{ pixel}^{-1}$), WFPC2 (FOV: $35'' \times 35''$; pixel scale: $0''.046 \text{ pixel}^{-1}$), or Advanced Camera for Surveys (ACS; FOV: $202'' \times 202''$; pixel scale: $0''.05 \text{ pixel}^{-1}$) cameras.

These high-resolution optical images allow a direct comparison between the optical and NIR nuclear morphology. We find that the optical nuclear regions are frequently more complex and fragmented than their IR counterparts, often exhibiting prominent dust lanes and patchy obscuration. Nuclear dust structures are commonly observed in nearby AGNs and merging systems (e.g., M. A. Malkan et al. 1998; L. K. Hunt & M. A. Malkan 2004).

In several targets without detected NIR substructure in the Keck imaging, the HST images reveal significant nuclear obscuration that can plausibly explain the observed SDSS/WISE positional offsets. In these systems, the SDSS centroid is likely biased toward regions of unobscured optical emission, rather than tracing the true location of the nuclear IR emission. As a result, dust obscuration can produce positional offsets even in the absence of multiple resolved IR nuclei. Examples of such systems are shown in Figure 13, where the SDSS/WISE offsets are aligned with nuclear dust lanes and obscured regions.

Conversely, several targets with confirmed NIR substructure also exhibit strong nuclear obscuration in the optical HST images. In these systems, one of the NIR nuclei is partially or completely obscured at optical wavelengths. Examples are shown in Figure 14, where the SDSS/WISE positional offset is consistent with one IR nucleus being heavily obscured in the optical. This suggests that optical obscuration can contribute to the observed positional offset even when multiple genuine nuclei are present.

To further quantify the effect of obscuration, we identified 18 mergers from the Expanded Keck AO Merger Sample ($0''.15 < \text{offset} < 6''$) that have both Keck and HST imaging. For each system, we counted the number of nuclear sources detected in the NIR and optical images and computed the ratio of IR to optical nuclear components.

Figure 15 shows the distribution of these ratios, separated by merger stage based on nuclear separation (above and below 3 kpc). We find that early-stage mergers (nuclear separations > 3 kpc) more frequently exhibit ratios near unity, indicating similar nuclear structures in the optical and IR. In contrast, late-stage mergers more commonly exhibit fewer detected IR nuclei relative to apparent optical sources, consistent with stronger nuclear obscuration.

In many cases, dust lanes fragment the optical emission, producing apparent multiple optical components that do not correspond to distinct IR nuclei. Conversely, genuine IR nuclei may be entirely obscured at optical wavelengths. These results demonstrate that optical imaging alone may either miss genuine nuclear components or misidentify obscured structures.

These findings provide important physical context for interpreting SDSS/WISE positional offsets. Optical obscuration can shift the SDSS centroid away from the true IR nucleus, producing measurable positional offsets. However, IR surveys such as UKIDSS and WISE are less affected by dust obscuration. As shown in Figure 16, offsets measured between IR surveys are more reliably associated with genuine dual nuclear components. This highlights the importance of NIR observations for identifying obscured nuclear substructure in studies of late-stage galaxy mergers.

4.7. Comparison to Other Works

To assess the effectiveness of our SDSS/WISE offset selection technique in identifying late-stage mergers with compact nuclear substructure, we compare our substructure detection fraction with previous high-resolution NIR imaging studies of advanced mergers conducted with Keck AO and HST. To enable a consistent comparison across samples, we adopt a primary–secondary flux ratio threshold of > 0.1 and restrict the analysis to projected nuclear separations < 3 kpc. We apply the flux ratio threshold only to compact nuclear components identified in the NIR images, excluding diffuse tidal features or ambiguous substructure. This threshold is directly comparable to the criteria used by M. J. Koss et al. (2018), who classified counterparts within 2.5 mag of the primary nucleus, corresponding to a flux ratio of ≈ 0.1 . We restrict the comparison to separations < 3 kpc, because the NIRC2 FOV limits our access to larger separations, ensuring that all samples are compared over a common and well-sampled physical separation range.

Under these criteria, our Primary Keck AO Merger Sample yields a substructure fraction of 34.8%, substantially higher

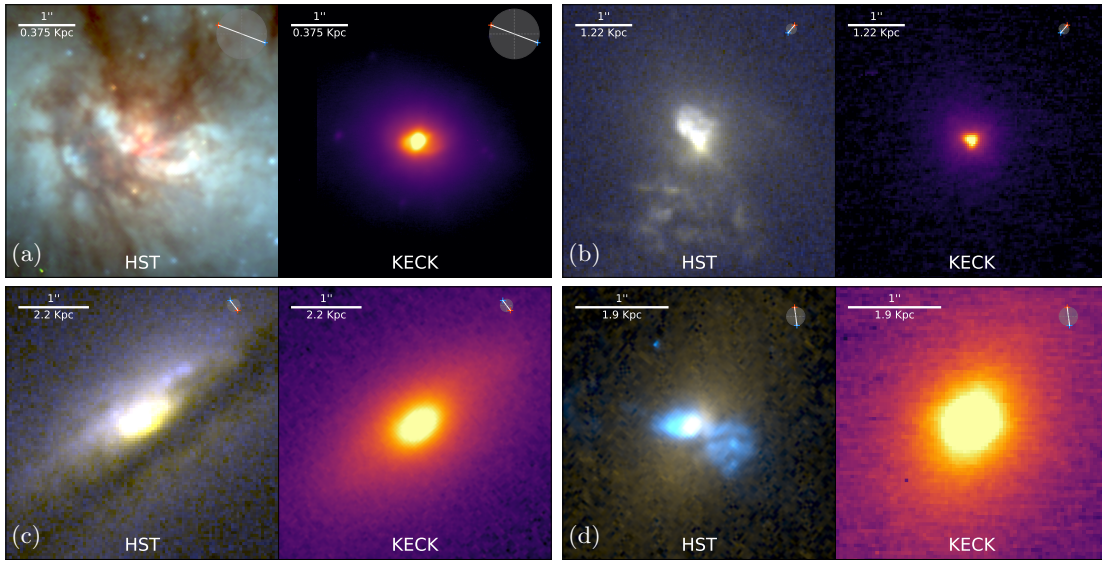


Figure 13. Examples of targets with no substructure whose SDSS/WISE offsets are likely caused by partial obscuration of their optical emission. For each target, we include the corresponding HST and Keck images. In the top right of each HST and Keck image, we include a representation of the SDSS/WISE offset that shows the orientation and length of the offset for that particular system. The targets of the top row—J083824 ((a) HST Program No. 9735) and J135429 ((b) HST Program No. 13513)—are from the Primary Keck AO Merger Sample, and the targets of the bottom row—J100654 ((c) HST Program No. 12754, Keck Program ID C221OL) and J165315 ((d) HST Program No. 13728, Keck Program ID H230N2L)—are from the Keck Nonmerger Comparison Sample.

than reported in samples selected using alternative approaches. In comparison, the Swift Burst Alert Telescope (BAT) hard-X-ray-selected obscured AGN sample of M. J. Koss et al. (2018), observed with Keck AO and HST NICMOS imaging, shows a substructure fraction of 17.6%. Similarly, the AO study of double-peaked [O III] AGNs by H. Fu et al. (2011a), which used GALFIT decomposition of NIR images to identify multiple nuclei, yields a substructure fraction of 8%. We also include the (ultra)luminous infrared galaxy (U)LIRG sample of S. Haan et al. (2011), based on HST NICMOS imaging of IR-luminous mergers, which shows a substructure fraction of 4.2% over the same separation range. These comparison samples span a range of selection methods, including hard-X-ray emission, optical emission-line kinematics, and IR luminosity, providing a broad context for evaluating the effectiveness of the SDSS/WISE offset selection technique.

We note, however, that this comparison carries important caveats. While M. J. Koss et al. (2018) employed a flux ratio threshold equivalent to the one adopted here, and H. Fu et al. (2011a) measured nuclear flux ratios using GALFIT decomposition of AO images, the photometric methodologies differ among studies. In our work, flux ratios are derived using aperture photometry centered on clearly resolved compact nuclei in NIR images. In contrast, other studies employ two-dimensional surface-brightness modeling or morphological classifications to identify nuclear counterparts. For the S. Haan et al. (2011) ULIRG sample, individual nuclear flux ratios are not published, preventing us from applying an identical flux ratio threshold; therefore, all morphologically identified nuclear pairs in their sample are included in our comparison. These methodological differences may introduce systematic uncertainties into the absolute substructure fractions. However, by restricting our analysis to compact nuclear components with flux ratios >0.1 and separations <3 kpc, we minimize differences in classification and ensure that the comparison focuses on physically comparable nuclear pairs.

Despite these limitations, the trend across all samples is suggestive. As shown in Figure 17, the SDSS/WISE-selected

Primary Keck AO Merger Sample exhibits the highest substructure fraction at the smallest projected separations (<0.5 kpc and <1 kpc), where the effects of dust obscuration and nuclear coalescence are expected to be strongest. Unlike hard-X-ray-selected or emission-line-based selection methods, which depend on detecting radiative signatures from potentially obscured AGN activity, the SDSS/WISE offset technique is sensitive to centroid shifts caused by unresolved, spatially distinct sources of emission, allowing it to identify compact nuclear pairs even when they are heavily obscured or unresolved in individual surveys. Because late-stage mergers are expected to contain closely separated, heavily obscured nuclei whose emission contributes differently at optical and IR wavelengths, centroid offsets between SDSS and WISE can potentially provide a direct observational signature of this phase, allowing the identification of compact nuclear pairs that trace the final stages of galaxy and SMBH coalescence.

While differences in photometric methodology, sample selection, and observational sensitivity prevent a strictly uniform comparison, the consistently higher substructure fraction observed in the SDSS/WISE-selected sample suggests that astrometric offset selection provides a powerful and complementary approach for identifying late-stage mergers containing closely separated nuclear components, particularly at subkiloparsec separations where other selection methods may be incomplete.

5. Summary and Conclusions

The goal of this work was to test a novel selection technique that leverages the astrometric precision of SDSS and WISE to identify unresolved nuclear substructure in late-stage, MIR-color-selected mergers using positional offsets between these two surveys. These systems probe a critical and poorly explored phase of galaxy evolution, where nuclear separations fall below ~ 1 kpc and the central SMBHs are expected to form gravitationally bound pairs and eventually merge. Such systems are particularly important for understanding BH

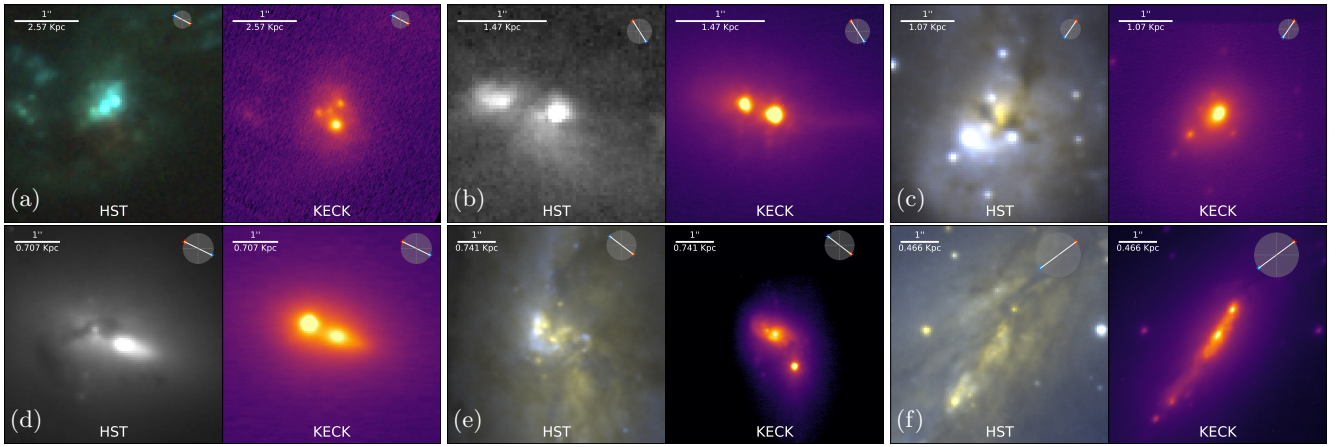


Figure 14. Examples of mergers with confirmed NIR substructure in Keck AO imaging but with one nucleus obscured or undetected in HST optical images. The SDSS/WISE positional offsets are consistent with one IR nucleus being partially obscured at optical wavelengths, demonstrating that dust obscuration contributes to the observed offsets.

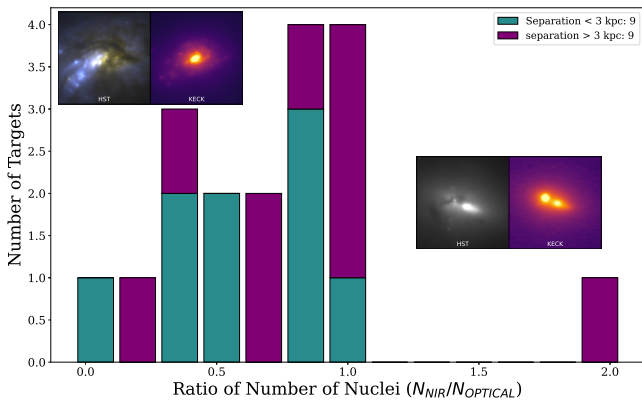


Figure 15. The distribution of the ratio of the number of apparent nuclear sources detected in the NIR (Keck NIRC2) to those detected in the optical (HST), separated based on merger separation (above and below 3 kpc) for targets in the Expanded Keck AO Merger Sample (53 systems) with both NIRC2 and HST imaging. This ratio quantifies the relative completeness of the optical and NIR observations in identifying nuclear components. Ratios above unity indicate systems in which one or more nucleus detected in the NIR are obscured or unresolved in the optical, while ratios near or below unity indicate similar or greater numbers of optical sources. This figure tests whether optical imaging alone reliably identifies nuclear components across different merger stages. Example systems J131534 and J131517 are shown to illustrate cases with ratios above and below unity, respectively.

growth, merger-driven fueling, and the formation of binary SMBHs, which are key targets for future gravitational-wave observatories such as LISA (P. Amaro-Seoane et al. 2017; M. Colpi et al. 2024).

To evaluate the effectiveness of this method, we conducted high-resolution AO imaging of the Primary Keck AO Merger Sample, consisting of 46 Galaxy Zoo mergers with red WISE colors ($W_1 - W_2 > 0.5$; L. Blecha et al. 2018) and significant SDSS/WISE positional offsets ($0.15 < \text{offset} < 1.5$). Our primary objective was to determine whether this offset-based selection reliably identifies mergers containing compact nuclear substructure at subkiloparsec scales.

The results of our analysis are summarized as follows:

1. A high substructure detection rate in the Primary Keck AO Merger Sample. We detect unresolved NIR substructure in 20 of the 46 targets (43.5%) in the Primary Keck AO Merger Sample. This demonstrates that SDSS/

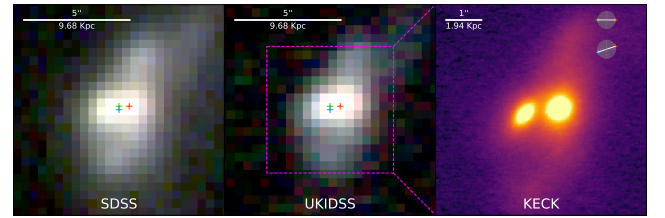


Figure 16. SDSS and Keck NIRC2 images of J001707—a system from the Primary Keck AO Merger Sample with subarcsecond offsets between its SDSS, UKIDSS, and WISE nuclear coordinates. The SDSS image shows the SDSS (blue), WISE (red), and UKIDSS (green) coordinates overlaid. At the top right of the NIRC2 image, we include representations of the SDSS/WISE and UKIDSS/WISE offsets corresponding to their sizes and orientations. The Keck NIRC2 image reveals dual NIR nuclei unresolved in SDSS. Both offsets trace the orientations of the dual nuclei, demonstrating that astrometric offsets between surveys can identify unresolved nuclear structure. Because UKIDSS operates at NIR wavelengths and provides accurate absolute astrometry, its centroid is less affected by dust obscuration than SDSS, strengthening the interpretation that the observed offsets reflect genuine nuclear substructure rather than obscuration-induced centroid shifts, highlighting the importance of IR observations for revealing compact nuclear components in late-stage galaxy mergers.

WISE positional offsets provide an efficient method for identifying mergers containing compact nuclear components unresolved in optical imaging. When restricting the analysis to compact nuclear components with flux ratios greater than 0.1 and separations below 3 kpc, consistent with criteria used in previous studies, our SDSS/WISE-selected sample exhibits a substructure fraction of 34.8%, substantially higher than reported for hard-X-ray-selected AGNs (M. J. Koss et al. 2018), double-peaked [O III] emitters (H. Fu et al. 2011a), and ULIRGs (S. Haan et al. 2011). This comparison suggests that astrometric offset selection is particularly effective at identifying compact nuclear pairs at the smallest separations.

2. SDSS/WISE offsets reliably trace genuine nuclear substructure. Although the limited FOV of the NIRC2 images prevents direct absolute astrometric registration, we find a strong correlation between both the PAs and magnitudes of the SDSS/WISE offsets and the separations and orientations of the substructure pairs detected in the Keck imaging. Furthermore, the detection rate of substructure does not decline toward smaller offsets, suggesting that the observed offsets are

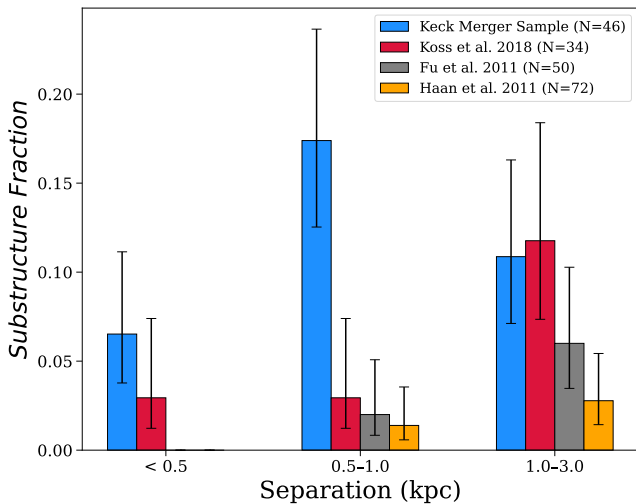


Figure 17. Fractions of targets with compact nuclear substructure detected in high-resolution NIR imaging from this work and from M. J. Koss et al. (2018), H. Fu et al. (2011a), and S. Haan et al. (2011), shown as a function of projected nuclear separation. To ensure a consistent comparison, only compact nuclear components with flux ratios >0.1 and separations <3 kpc are included for all samples where such measurements are available. For the S. Haan et al. (2011) sample, individual nuclear flux ratios are not published, and all morphologically identified nuclear pairs within this separation range are included. The error bars denote 1σ binomial CIs. Despite differences in selection techniques and photometric methodologies, the SDSS/WISE offset-selected merger sample exhibits a higher fraction of compact nuclear substructure at separations below 1 kpc, suggesting that the offset method is effective at identifying the most compact and obscured merger phases.

not dominated by astrometric noise but instead reflect genuine nuclear substructure over the full range of offsets explored. However, we emphasize that a definitive assessment of the contribution from astrometric uncertainties requires a comparison to simulations or mock catalogs, which is beyond the scope of this work.

3. Optical obscuration contributes to SDSS/WISE positional offsets. For targets for which no NIR substructure is detected, archival HST optical imaging reveals that many SDSS/WISE offsets arise from partial obscuration of the nuclear region. Dust lanes and obscured emission bias the SDSS optical centroid away from the true nucleus, while the IR WISE centroid more accurately traces embedded emission. In several systems, nuclear components visible in the IR are partially or completely absent in optical imaging, demonstrating that optical surveys alone can fail to identify closely separated nuclei in heavily obscured mergers.
4. Substructure is preferentially associated with highly obscured systems. Targets containing NIR substructure exhibit systematically higher extinction values, as measured by $E(B - V)$, compared to systems without detected substructure. This trend supports a physical picture in which the latest merger stages are characterized by high obscuration, which both facilitates nuclear inflows and obscures nuclear components at optical wavelengths.
5. Comparison samples confirm the importance of both merger classification and astrometric offset selection. We constructed a Keck Nonmerger Comparison Sample of 40 galaxies selected using identical WISE color, magnitude, and SDSS/WISE offset criteria, but not

classified as mergers by Galaxy Zoo. We detect substructure in 25% of these systems, demonstrating that SDSS/WISE offsets alone can reveal unresolved nuclear components even in systems lacking clear morphological merger signatures in optical imaging. To isolate the role of the offset requirement itself, we also constructed a Nonoffset Merger Comparison Sample consisting of mergers with identical WISE color and magnitude criteria but negligible SDSS/WISE offsets (<0.15). Only one system in this sample exhibits substructure, demonstrating that the offset requirement significantly enhances the efficiency of identifying unresolved nuclear components.

6. Substructure is preferentially found in systems with signatures of nuclear activity. Targets containing substructure are preferentially associated with AGN or composite classifications based on optical emission-line diagnostics and exhibit redder MIR colors indicative of obscured nuclear activity. In particular, 89% of targets with $W_2 - W_3 > 4.2$ exhibit NIR substructure, consistent with expectations that late-stage mergers are characterized by both enhanced accretion and obscured star formation activity.

The combined optical and IR observations presented in this work demonstrate that large-area optical surveys alone are not sufficient for identifying compact nuclear pairs in heavily obscured mergers. IR imaging is essential for probing this critical stage of galaxy evolution. Future IR missions, including the Nancy Grace Roman Space Telescope, will enable this astrometric offset technique to be applied over much larger volumes and to lower-mass systems, providing powerful new constraints on the late stages of galaxy mergers and the formation of binary SMBHs.

Follow-up spatially resolved spectroscopy is required to determine the nature of the individual nuclear components and confirm the presence of dual AGNs. Follow-up OH-Suppressing Infrared Imaging Spectrograph (OSIRIS) K-band Integral Field Spectroscopy (IFS) observations of a subset of the sample will be presented by M. McDonald et al. 2026, in preparation. Regardless of whether all systems host dual AGNs, identifying closely separated nuclei in late-stage mergers provides crucial insight into BH growth, galaxy evolution, and the processes leading to gravitational-wave emission.

Acknowledgments

We thank the anonymous referee for a careful and constructive report that significantly improved the clarity, organization, and presentation of this work. The referee's detailed suggestions led us to strengthen the discussion of methodological caveats, streamline and reorganize the figures, clarify the interpretation of the photometric measurements and comparison samples, and improve the overall presentation of the results. We particularly appreciate the referee's thoughtful comments regarding the separation of morphological classes, the treatment of flux ratios, and the framing of comparisons to previous studies, all of which helped us present the analysis in a clearer and more rigorous way. C.V. acknowledges support from the Presidential Scholarship from George Mason University. R.W.P. gratefully acknowledges support through an appointment to the NASA Postdoctoral Program at the

Goddard Space Flight Center, administered by ORAU through a contract with NASA. Basic research in radio astronomy at the U.S. Naval Research Laboratory is supported by 6.1 Base Funding. The work of J.M.C. was supported by NASA under award No. 80GSFC24M0006. F.M.-S. acknowledges support from NASA through award 80NSSC23K1529. The research of J.D.M. was supported by an appointment to the NASA Postdoctoral Program at the NASA Goddard Space Flight Center, administered by Oak Ridge Associated Universities under contract with NASA. S.S., G.C., and V.U. performed part of this work at the Aspen Center for Physics, which is supported by NSF grant PHY-2210452. The work of S.D. was supported by the National Science Foundation Graduate Research Fellowship Program under Grant Number DGE-2236637. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

This research made use of Astropy,²⁴ a community-developed core Python package for Astronomy (Astropy Collaboration et al. 2013), as well as TOPCAT (M. B. Taylor 2005). The geometrical distortion correction code was run on the ARGO and HOPPER research computing clusters provided by the Office of Research Computing at George Mason University, VA: <https://orc.gmu.edu>.

Some of the data presented herein were obtained at the Keck Observatory, which is a private 501(c)3 nonprofit organization operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation. The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Maunakea has always had within the Native Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain. This research has made use of the Keck Observatory Archive (KOA), which is operated by the W. M. Keck Observatory and the NASA Exoplanet Science Institute (NExScI), under contract with the National Aeronautics and Space Administration.

Funding for the Sloan Digital Sky Survey (SDSS) and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS website is <http://www.sdss.org/>. SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are the American Museum of Natural

History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, the University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, the Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

The HST data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST) at the Space Telescope Science Institute. The specific observations analyzed can be accessed via doi:[10.17909/dazg-en96](https://doi.org/10.17909/dazg-en96). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support to MAST for these data is provided by the NASA Office of Space Science via grant NAG5-7584 and by other grants and contracts.

This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration.

The UKIDSS project is defined in A. Lawrence et al. (2007). UKIDSS uses the UKIRT Wide Field Camera (WFCAM; M. Casali et al. 2007) and a photometric system described in P. C. Hewett et al. (2006). The pipeline processing and science archive are described in M. J. Irwin (2008) and N. C. Hambly et al. (2008). We have used data from the ninth data release, which is described in detail in A. Lawrence et al. (2007).

Software: Astropy (Astropy Collaboration et al. 2013, 2018, 2022), NumPy (C. R. Harris et al. 2020), SciPy (P. Virtanen et al. 2020), TOPCAT (M. B. Taylor 2005).

Appendix A

Comparison of Sample Properties between Primary Keck AO Merger Sample and Keck Nonmerger Comparison Sample

Here we compare the distributions of SDSS/WISE offset, redshift, optical extinction, W_1 , and $W_1 - W_2$ for the Primary Keck AO Merger Sample and the Keck Nonmerger Comparison Sample in Figure A1. Two-sample KS tests show no statistically significant differences between the samples in these properties, indicating that the two samples are well matched in the observational properties relevant to our sample selection criteria.

²⁴ <http://www.astropy.org>

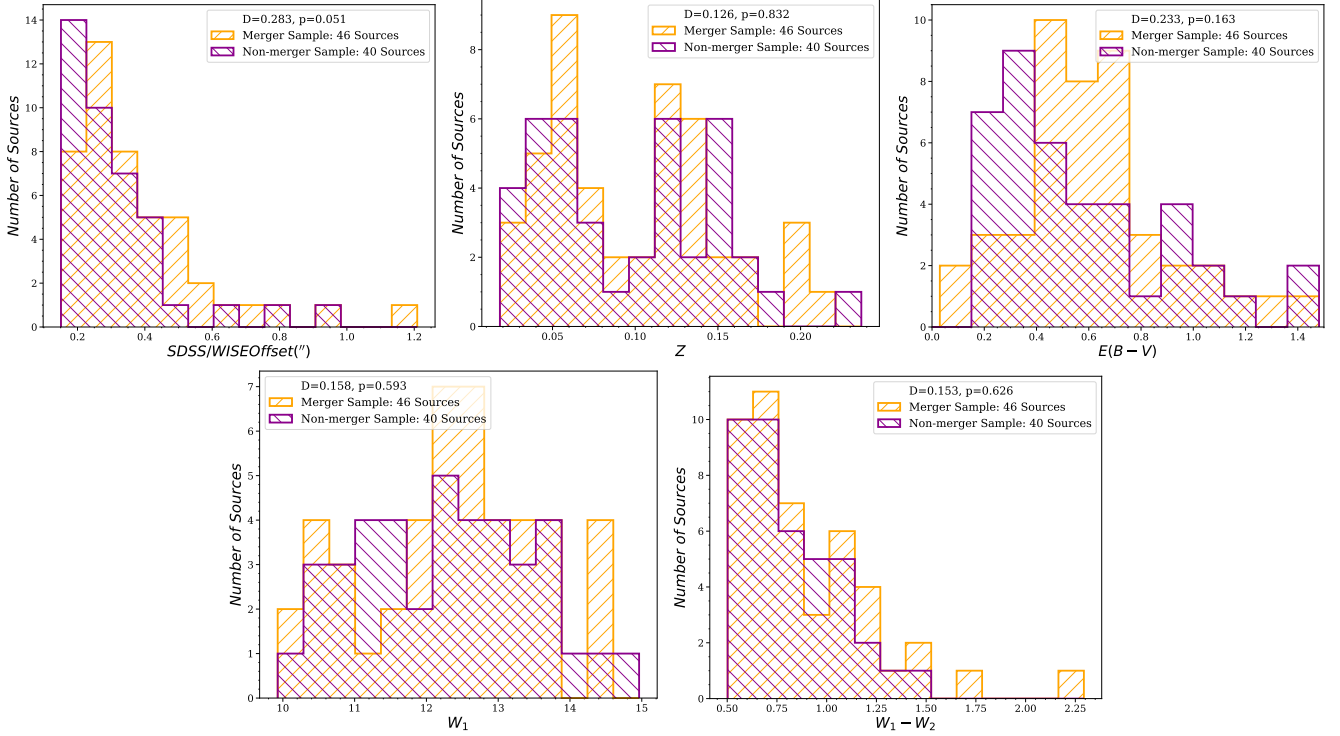


Figure A1. Comparisons of the SDSS/WISE offset (top left), redshift (top middle), $E(B - V)$ (top right), W_1 (bottom left), and $W_1 - W_2$ (bottom right) distributions for the Primary Keck AO Merger Sample (46 systems) and the Keck Nonmerger Comparison Sample (40 systems with archival Keck AO imaging). KS tests show no statistically significant differences between the two samples in the parameters relevant to our sample selection. This suggests that differences in substructure detection rates may not be due to systematic differences in these parameters. The KS statistic (D) and corresponding p -value for each comparison are listed in the legend.

Appendix B

Summary of NIRC2 Observations

Table 4 summarizes the observing conditions for the 36 nonarchival targets in the Primary Keck AO Merger Sample observed with NIRC2 in the K_p band.

Table 4
Summary of the NIRC2 K_p -band Observations of the 36 Nonarchival Targets in the Primary Keck AO Merger Sample

SDSS Name	Observation Date (UT)	t_{exp} (s)	Airmass	Seeing (arcsec)	PSF (arcsec)
Narrow Camera Observations ($0.009952 \text{ pix}^{-1}$)					
J015028.40+130858.4	2021-09-19	2940	1.01	0.5	0.097
J082312.61+275139.8	2022-03-18	900	1.03	0.7	0.038
J083824.00+254516.3	2022-03-19	900	1.08	1.0	0.071
J084344.98+354942.0	2022-03-19	900	1.08	1.0	0.048
J090025.37+390353.7	2022-03-19	900	1.07	1.0	0.052
J091529.62+090601.5	2022-03-19	900	1.02	1.0	0.046
J093314.80+630945.0	2022-03-18	900	1.38	0.7	0.049
J093551.60+612111.3	2022-03-19	900	1.33	1.0	0.102
J101653.82+002857.0	2022-03-19	900	1.06	1.0	0.083
J101833.64+361326.6	2022-03-18	900	1.16	1.0	0.078
J105705.40+580437.4	2022-03-19	900	1.30	1.0	0.074
J110213.01+645924.8	2022-03-18	900	1.46	0.7	0.049
J120149.75-015327.5	2022-03-18	900	1.22	0.7	0.052
J120408.82+132117.0	2022-03-19	2100	1.11	1.0	0.052
J121522.77+414620.9	2022-03-18	900	1.16	0.7	0.046
J124117.64+273252.3	2022-03-18	900	1.10	0.7	0.049
J124136.22+614043.4	2022-03-18	900	1.36	0.7	0.127
J124406.61+652925.2	2022-03-19	900	1.43	1.0	0.151
J131701.41+004509.7	2022-03-18	600	1.10	0.7	0.071
J133032.00-003613.5	2022-03-18	900	1.09	0.6	0.044

Table 4
(Continued)

SDSS Name	Observation Date (UT)	t_{exp} (s)	Airmass	Seeing (arcsec)	PSF (arcsec)
J134651.82+371231.0	2022-03-18	900	1.05	0.6	0.088
J135255.67+252859.6	2022-03-18	900	1.00	0.6	0.055
J142742.68+050318.4	2022-03-19	900	1.03	1.0	0.090
J150517.88+080912.7	2022-03-18	900	1.03	0.6	0.064
J151747.47+334740.4	2022-03-19	900	1.03	1.0	0.041
J151806.13+424445.0	2022-03-18	900	1.09	0.6	0.049
J151907.33+520606.0	2022-03-19	900	1.19	1.0	0.051
J152659.44+355837.0	2022-03-19	900	1.04	1.0	0.081
J153142.10+051801.6	2022-03-19	900	1.07	1.0	0.120
J153954.78+272758.7	2022-03-19	900	1.04	1.0	0.056
J161708.95+222627.9	2022-03-18	900	1.00	0.6	0.052
J165306.55+262638.0	2022-03-18	900	1.01	0.6	0.049
Wide Camera Observations ($0''.039686 \text{ pix}^{-1}$)					
J001707.95+011506.3	2021-09-19	1080	1.09	0.5	0.190
J010942.21-004417.4	2021-09-19	330	1.09	0.5	0.376
J013720.02+005722.2	2021-09-19	1140	1.07	0.5	0.108
J033037.40-003304.0	2021-09-19	1140	1.09	0.5	0.179

Note. The PSF column corresponds to the FWHM of the tip-tilt stars acquired immediately before each science exposure.

Appendix C Substructure Targets

In the following section, we present the results and analysis for all 20 targets with substructure detected with NIRC2 imaging. In Figures C1–C20, we show for each target its SDSS gri image, NIRC2 image, and, when available, its UKIDSS YHK image and/or HST image; for targets with HST observations in multiple filters, we show a three-color image. Each image is aligned with north pointing up and east to the left. For each SDSS and UKIDSS image, we include a white scale bar—corresponding to $5''$ —in the top left and overlay the system’s SDSS coordinate in blue and WISE coordinate in red. We also include a magenta square in either/both the SDSS and UKIDSS images corresponding to the size and location of the Keck image cutout and HST image cutout, when available. In each NIRC2 and HST image, we include a white scale bar—corresponding to $1''$ —in the top left and a visual representation of the SDSS/WISE offset in the top right, corresponding to the distance between the SDSS (blue) and WISE (red) coordinates and their orientation relative to each other. We do not present the locations of the SDSS and WISE coordinates in these images because there are no stars within the FOVs of the images and thus we are unable to spatially map between detector pixels and sky coordinates.

C.1. J001707+011506

NIRC2 imaging of J001707 reveals that it contains clear dual nuclei separated by $0''.986$ or 1.910 kpc with a PA of 99.51° . In both SDSS and UKIDSS, these nuclei are blended into a single apparent nucleus elongated along the direction of the two nuclei. The host galaxy exhibits bipolar tidal tails extending out to $\sim 12.4 \text{ kpc}$ in the north and $\sim 5.6 \text{ kpc}$ in the south. The SDSS/WISE offset detected in this target has a separation of $0''.511$ and a PA of 108.6° . The SDSS/WISE offset detected in this merger system clearly corresponds to the dual nuclei, as the PAs of the SDSS/WISE offset and nuclear

pair are very similar, although the separation of the nuclei is underpredicted by the SDSS/WISE offset (see Section 4.4; $\Delta\text{Sep.} = 0''.475$ and $\Delta\text{PA} = 9.09^\circ$). The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color-color diagram, suggesting it is a candidate dual AGN.

C.2. J010942–004417

J010942 appears to be a highly disturbed galaxy undergoing a merger with a companion $10''$ or 16.57 kpc to the southwest. J010942 appears to contain a single elongated nucleus in both SDSS and UKIDSS, whereas the companion contains two semiresolved nuclei. High-resolution NIRC2 imaging of this target reveals two nuclei and confirms the presence of two nuclei in the companion. Inspection of SDSS DR16 spectra of J010942 and its companion reveals a velocity difference of $\sim 70 \text{ km s}^{-1}$, suggesting that they are associated with each other, although higher-resolution spectroscopic follow-up is required for confirmation (M. McDonald et al. 2026, in preparation). The two nuclei in J010942 are separated by $1''.129$ or 1.871 kpc , with a PA of 246.3° . The SDSS/WISE offset detected in the target has a separation of $0''.443$ and a PA of 225° , which underpredicts the separation of the dual nuclei (see Section 4.4) but more closely follows the orientation of the nuclei (i.e., $\Delta\text{Sep.} = 0''.686$ and $\Delta\text{PA} = 21.30^\circ$). Comparison between the SDSS and UKIDSS cutout images of this target shows that the apparent nuclei of the optical and NIR emission of this target are clearly offset from each other and thus driving the SDSS/WISE offset. However, high-resolution optical imaging is required to determine whether this discrepancy is caused by partial obscuration or an inherent difference in the emission properties of the two nuclei. The host galaxy of J010942 is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and outside

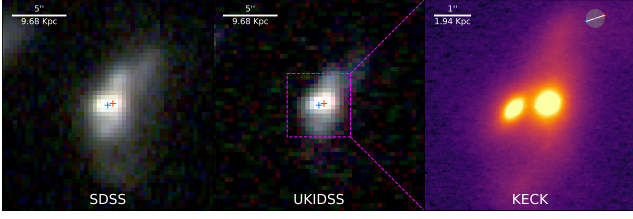


Figure C1. The images provided above are described at the beginning of Appendix C.

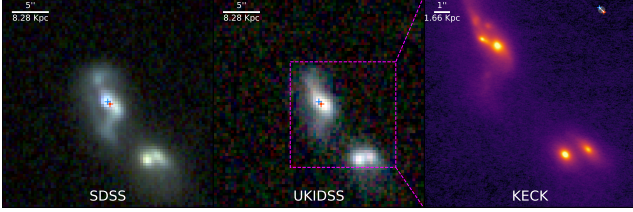


Figure C2. The images provided above are described at the beginning of Appendix C.

the Jarrett AGN region of our WISE color–color diagram, which may suggest that these two nuclei are not dual AGNs but rather a single AGN and a non-AGN (i.e., an inactive SMBH or SF region).

C.3. J015028+130858

J015028 is a merger system with a galaxy pair in the east and west of the SDSS cutout image; only the western galaxy is visible in UKIDSS, separated by $3''.742$ or 9.60 kpc. We detect an SDSS/WISE offset in this western galaxy, with a separation of $0''.275$ and a PA of 62.35° , and thus consider it to be the target galaxy for this analysis. High-resolution NIRC2 imaging of the target reveals three sources of significant NIR emission in the central nuclear region, forming a triangle with a bright southern source and two dimmer sources to the northeast and northwest. Inspection of the archival HST WFC3 imaging of this target (Program No. 12310; F390W, F475W, and F850LP) reveals that the brightest source in the NIR is not visible at optical wavelengths, most likely due to obscuration from dust. Based on the orientation of the substructure in the NIR and optical, it can also be seen that there is a fourth source of emission seen in the HST image that corresponds to the region between the two northern sources in the NIRC2 image. The orientation of the SDSS/WISE offset visually suggests that the WISE coordinate is tracing the position of the bright southern source of NIR emission and the SDSS coordinate is tracing the unobscured optical emission in the north, creating the SDSS/WISE offset we detect. Our comparison of the separation and PA of the SDSS/WISE offset with the substructure in this target yielded very similar separations but a significant difference in PA (i.e., $\Delta\text{Sep.} = 0''.054$ and $\Delta\text{PA} = 106.8^\circ$). This is due to the fact that the substructure pair is defined based on the brightest secondary source of NIR emission, which in this case is not necessarily the brightest secondary source of optical emission. The host galaxy of J015028 is optically classified as an S_{06} -type AGN in the MPA-JHU catalog. Additionally, it lies within the SF classification of our BPT diagram and outside the Jarrett AGN region of our WISE color–color diagram,

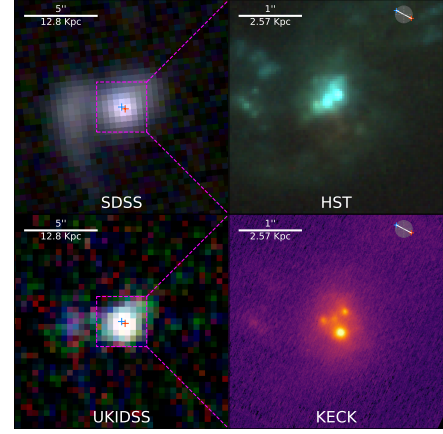


Figure C3. The images provided above are described at the beginning of Appendix C.

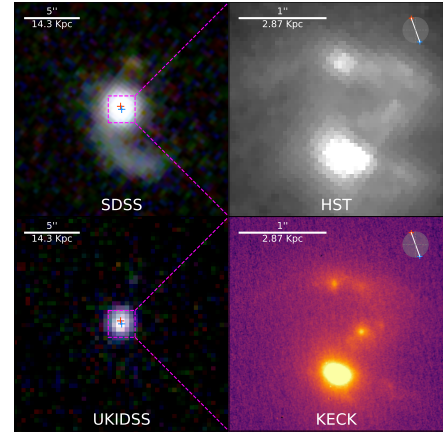


Figure C4. The images provided above are described at the beginning of Appendix C.

which may suggest that the compact sources of emission in this target are SF regions rather than galaxy nuclei or AGNs.

C.4. J082312+275140

NIRC2 imaging of J082312 reveals three potential nuclei connected by an arc of emission. There is a clear primary nucleus and two secondary nuclei, northwest from the primary at a distance of $0''.56$ and north from the primary at a distance of $1''.06$, with PAs of 331.030° and 2.440° , respectively. The host galaxy, as seen in SDSS, exhibits a tidal tail that extends out to ~ 25 kpc and curves toward the west, but in UKIDSS it is a point source. The HST WFC2 imaging survey conducted by K. D. Borne et al. (1999) included F814w observations of J082312. The same arc of emission and broad tidal tail can be seen in the HST image, but only two of the three nuclei are visible with a pair separation of $\sim 1''$, indicating that the northwestern nucleus is obscured. The northwestern nucleus is the brightest of the secondary nuclei, thus we identify the primary and this secondary nucleus as the substructure pair in this target. The SDSS/WISE coordinate offset has a separation of $0''.294$ and a PA of 199.741° . Although the orientation of the SDSS/WISE offset does not seem to trace that of the substructure pair, it appears to have a similar orientation to that of the more separated secondary. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-

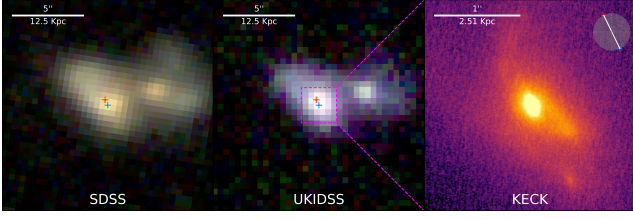


Figure C5. The images provided above are described at the beginning of Appendix C.

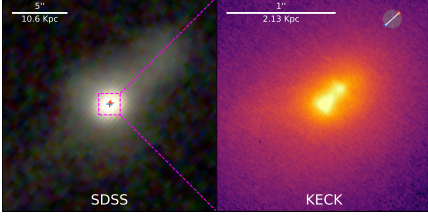


Figure C6. The images provided above are described at the beginning of Appendix C.

JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and outside the Jarrett AGN region of our WISE color–color diagram.

C.5. J091529+090601

J091529 is a close galaxy pair separated by $3''.344$ and 8.392 kpc; the nuclei of both galaxies are resolved in the SDSS, UKIDSS, and NIRC2 images. The high-resolution NIRC2 imaging of this target reveals previously unresolved substructure near the primary central nucleus of the eastern galaxy. Surrounding this nucleus, we can see faint emission consistent with bipolar tidal tails curving into the north and southwest, most likely generated by the ongoing galaxy merger. There is one faint secondary source of emission within a $1''.5$ radius of the primary central nucleus of the eastern galaxy. This substructure lies at a distance of $0''.917$ or 2.300 kpc southwest from the primary, with a PA of $205''.302$. Although this substructure does not appear to be a secondary nucleus, it does seem to trace the SDSS/WISE offset. The SDSS/WISE offset underpredicts the separation of the substructure, as expected (see Section 4.4), with a separation of $0''.431$, but the PA of $205''.880$ is very similar to that of the substructure pair. We note that there is another SDSS/WISE offset detected in this merger system, with a separation of $3''.066$ between the SDSS coordinate of the eastern galaxy and the WISE coordinate that coincides with the position of the western galaxy. Since this offset is resolvable by SDSS and UKIDSS and corresponds to a secondary galaxy resolvable by SDSS, we do not consider it a detection of substructure in the target galaxy. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color–color diagram.

C.6. J093314+630945

J093314 is an advanced merger system that appears to contain a single nucleus with multiple tidal tails in its SDSS image. The tidal tails extend in opposite directions without much curvature out to distances of ~ 30 kpc and ~ 15 kpc. The

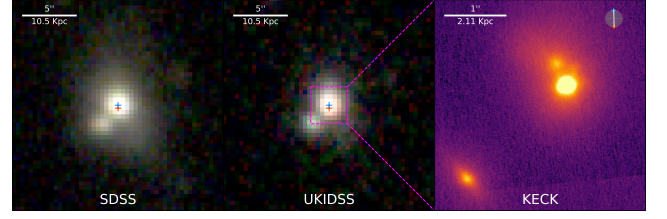


Figure C7. The images provided above are described at the beginning of Appendix C.

NIRC2 imaging reveals two apparent nuclei at a separation of $0''.190$ or 0.405 kpc, with a PA of $316''.231$. The separation and PA of the SDSS/WISE offset detected in this target are $0''.167$ and $311''.876$, respectively. It is clear that our offset selection detected unresolved dual nuclei in this system, but it is also closely traced by the actual separation and PA between these nuclei (i.e., $\Delta\text{Sep.} = 0''.023$ and $\Delta\text{PA} = 4''.355$). The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color–color diagram, suggesting this may be a candidate dual-AGN system.

C.7. J101653+002856

J101653 is a close galaxy pair separated by $2''.26$ or 4.76 kpc, with the nuclei of both galaxies resolved in SDSS and UKIDSS. This target has been previously identified as an elliptical galaxy within a disturbed pre-coalescence system (J. C. S. Pierce et al. 2023). The detected SDSS/WISE offset is in the northwestern galaxy of this pair. The NIRC2 imaging of the northwestern galaxy reveals a third source of emission very close to its primary central nucleus. The separation between this close pair is $0''.350$ or 0.737 kpc, with a PA of $25''.195$. The separation and PA of the SDSS/WISE offset are $0''.275$ and $1''.251$, respectively. The size and PA of the SDSS/WISE offset are similar to those of the substructure pair, although with less accuracy than other targets in this sample. Additionally, we note that based on the orientation of the offset, it appears that the WISE coordinate corresponds to the primary central nucleus and the SDSS coordinate corresponds to the secondary nucleus. This may suggest that the primary nucleus is obscured, but higher-resolution optical imaging is required to confirm this. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color–color diagram.

C.8. J110213+645925

J110213 is a candidate dual-AGN system containing clear subkiloparsec dual nuclei with a separation of $0''.357$ or 0.524 kpc and a PA of $70''.923$. This is a late-stage merging system with one apparent nucleus detected in SDSS. One prominent tidal tail extends $17''.5$ out to the east and curves toward the north and back into the center of the galaxy, forming a closed loop. D. Zhao et al. (2019) imaged this target with the HST WFC3 camera (F105W and F438W), classifying it as a type 2 quasar within a merging system. Upon inspection of the HST images, two nuclei are visible, with an apparent dust lane between them. However, these nuclei have much

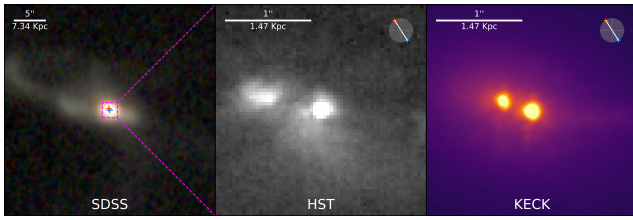


Figure C8. The images provided above are described at the beginning of Appendix C.

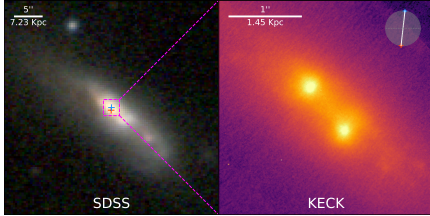


Figure C9. The images provided above are described at the beginning of Appendix C.

more irregular shapes than those seen in our Keck image, and the separation of the apparent nuclei in the optical F438W image is $\sim 0''.67$. It is possible that the dust lane is partially obscuring one of the nuclei in the optical image, causing this discrepancy. If we assume the western nucleus is the same source in both the NIRC2 and HST image, then the location of the eastern nucleus (in the NIRC2 image) coincides with the dust lane. Furthermore, we note that based on the orientation of the SDSS/WISE offset, the WISE coordinate coincides with the obscured eastern nucleus and the Galaxy Zoo position coincides with the western nucleus. An obscuration of the eastern nucleus would best account for the orientation and positioning of the offset, since the eastern nucleus would only be detected in WISE. Additionally, the separation and PA of the SDSS/WISE offset in J110213 are $0''.276$ and $32^\circ.363$, respectively, which are similar to the separation and PA of the dual nuclei. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color-color diagram, making this a strong candidate dual-AGN system.

C.9. J120408+132116

J120408 is a candidate dual-AGN system containing two clear nuclei at a separation of $0''.740$ or 1.070 kpc and a PA of $219^\circ.846$. SDSS imaging of this target shows an elongated galaxy with one apparent optical nucleus and a highly extended ($>10''$) tidal tail extending to the northeast. The SDSS/WISE offset for this target has a separation of $0''.486$ and a PA of $173^\circ.630$. This does not trace the observed properties of the dual nuclei well, but nonetheless it was able to detect them within an apparent single-nuclei system. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

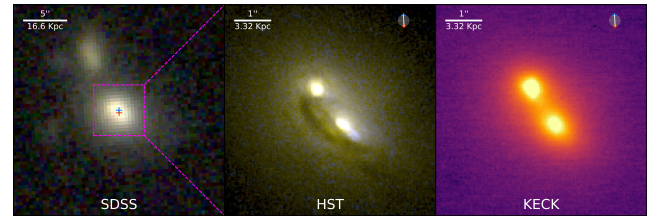


Figure C10. The images provided above are described at the beginning of Appendix C.

C.10. J123915+531414

J123915 is one of the targets in the Primary Keck AO Merger Sample that has publicly available NIRC2 imaging available in the Keck archive (see Section 3.4). H. Fu et al. (2011a) conducted Keck LGSAO observations of this target with the NIRC2 Wide-Field Camera (FOV: $40'' \times 40''$; pixel scale: $0.039686 \text{ pixel}^{-1}$) in the K_p filter, as part of an observing program searching for kiloparsec-scale dual AGNs in double-peaked [OIII] AGNs. Additionally, this target was included in HST F438W and F814W observations of AGNs with double-peaked narrow emission lines presented in J. M. Comerford et al. (2015), where they identify J123915 as a candidate dual AGN. The SDSS imaging of this target shows a galaxy with an unresolved and elongated bright central nucleus, with a nearby galaxy in the northeast likely to be unassociated ($\Delta v \sim 14,800 \text{ km s}^{-1}$). In both the NIRC2 and HST imaging, we see clear dual nuclei at a separation of $1''.161$ or 3.855 kpc and a PA of $213^\circ.349$, as measured in the NIRC2 image. In the HST image, there is a clear dust lane appearing to encircle and partially obscuring the southwestern nucleus. The SDSS/WISE offset detected in this system has a separation of $0''.306$ and a PA of $183^\circ.300$, poorly tracing the orientation and separation of the two nuclei (i.e., $\Delta \text{Sep.} = 0''.855$ and $\Delta \text{PA} = 30^\circ.049$). The SDSS/WISE offset may be tracing the obscuring dust lane, with the SDSS coordinate coinciding with the region between the two nuclei, but above the obscuring dust and the WISE coordinate coinciding with the region between the two nuclei obscured by the dust lane. Interestingly, J. M. Comerford et al. (2015) show that the double-peaked emission lines seen in J123915 correspond to two [O III] $\lambda 5007$ emission components separated by $0''.39$, which is similar to the separation of the SDSS/WISE offset we detect. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

C.11. J124117+273251

J124117 is the northeastern galaxy in a close galaxy pair separated by $2''.44$ or 6 kpc, in which we detect a coordinate offset. Both galaxies are visible in the NIRC2 imaging, with the galaxy of interest (northeast) containing a complex nuclear region with multiple compact sources of emission within the central arcsecond of the galaxy. The galaxy pair can be seen in SDSS and UKIDSS, but the substructure in J124117 is unresolved in both surveys. The resolved substructure does not appear to be clear nuclei, such as those in J110213 or J120408; the emission seems more consistent with extended nuclear emission that is partially obscured by a dust lane. Although

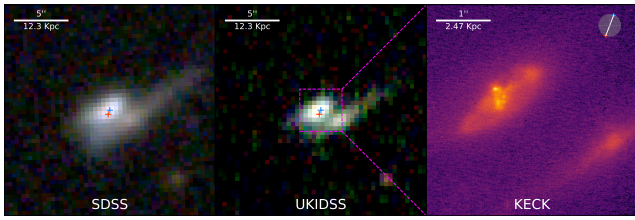


Figure C11. The images provided above are described at the beginning of Appendix C.

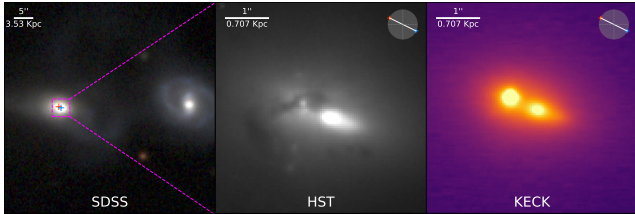


Figure C12. The images provided above are described at the beginning of Appendix C.

this target does not contain clear dual nuclei, it does contain subarcsecond structure that seems to be traced by the offset measurement. The SDSS/WISE offset detected in this system has a separation of $0''.411$ and a PA of $158^\circ.881$. Within the nuclear region of the primary galaxy, we see two prominent “blobs” forming a substructure pair, with a separation of $0''.266$ or 0.655 kpc and a PA of $193^\circ.076$. The orientation of the SDSS/WISE offset does not appear to trace that of the candidate pair very well, but it may be that the SDSS coordinate is biased toward the more extended emission in the galaxy (in the northwest) and the WISE coordinate is more accurately detecting the bright nuclear emission in the south. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

C.12. J131517+442425

J131517 is one of the targets in the Primary Keck AO Merger Sample that has publicly available NIRC2 imaging in the Keck archive (see Section 3.4). Keck LGSAO observations of this target were conducted with the NIRC2 Wide-Field Camera (FOV: $40'' \times 40''$; pixel scale: $0''.039686 \text{ pixel}^{-1}$) in the K_p filter as part of Keck observing program Y076 in 2022. Additionally, this target was included in the HST F814W observations of Swift/BAT AGNs presented in M. Kim et al. (2021). In the SDSS cutout image, we see that this target is part of an early-stage merger system at a separation of $36''.438$ or 25.744 kpc, with the eastern galaxy being the galaxy in which we detect an SDSS/WISE offset. The high-resolution NIRC2 imaging reveals clear dual nuclei separated by $0''.711$ or 0.503 kpc and a PA of $244^\circ.142$. The SDSS/WISE offset, with a separation of $0''.689$ and a PA of $243^\circ.980$, very closely traces the orientation of the nuclear pair (i.e., $\Delta\text{Sep.} = 0''.022$ and $\Delta\text{PA} = 0^\circ.162$). Inspection of the HST F814W image of J131517 reveals that the eastern nucleus of this pair is almost entirely obscured by a dust lane, which appears to be causing the significant offset between the WISE and SDSS nuclear coordinates. Furthermore, the orientation of the SDSS/WISE

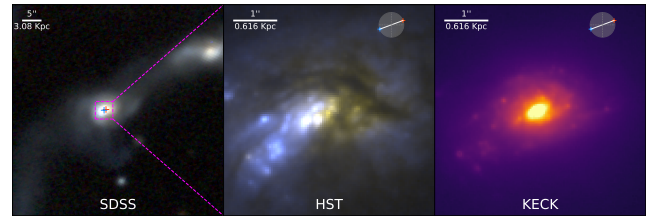


Figure C13. The images provided above are described at the beginning of Appendix C.

offset suggests that the WISE coordinate coincides with the optically obscured eastern nucleus and the SDSS coordinate coincides with the unobscured western nucleus. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and within the Jarrett AGN region of our WISE color-color diagram.

C.13. J131534+620728

J131534 is one of the targets in the Primary Keck AO Merger Sample that has publicly available NIRC2 imaging in the Keck archive (see Section 3.4). Keck LGSAO observations of this target were conducted with the NIRC2 Wide-Field Camera (FOV: $40'' \times 40''$; pixel scale: $0''.039686 \text{ pixel}^{-1}$) in the K_s ($\lambda_c = 2.146 \mu\text{m}$) filter as part of Keck observing program Z229 in 2017. Additionally, this target was included in the Great Observatories All-Sky LIRG Survey (GOALS) HST sample (L. Armus et al. 2009), where it was imaged with ACS/WFC using the F435W and F814W filters (GO program 10592; PI: A. Evans). In the SDSS image, we see that this target is part of an early-stage merger system at a separation of $35''$ or 21.553 kpc, with the eastern galaxy being the galaxy in which we detect an SDSS/WISE offset. The eastern galaxy has two prominent tidal tails: one extending 24.6 kpc to the southeast and the other connecting the two galaxies. In the NIRC2 imaging of this target, we see that there is a single bright central nucleus or AGN surrounded by many sources of faint secondary emission or substructure. Based on the criteria laid out in Section 4.1, the substructure pair we identify in this target for comparison with the SDSS/WISE offset consists of the central nucleus and a small source of emission north of the nucleus at a separation of $0''.287$ or 0.177 kpc and a PA of $343^\circ.328$. The SDSS/WISE offset, with a separation of $0''.585$ and a PA of $290^\circ.428$, does not appear to trace the substructure pair we define, but comparison between the HST and Keck imaging reveals that the SDSS/WISE offset reflects a difference in the NIR and optical emission of J131517 rather than real substructure revealed by NIR imaging. The HST image shows that there is a significant amount of dust obscuring the western half of the optical nuclear emission. By identifying matching sources of secondary emission visible in both the Keck and HST images, we find that the central NIR nucleus is likely spatially coincident with the large dust cloud in the western region of the optical nuclear emission and not the bright optical emission we see. This suggests that the SDSS/WISE offset we detect is caused by the central nucleus or AGN being obscured by dust and thus biasing the SDSS coordinate away from the true location of the AGN. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the

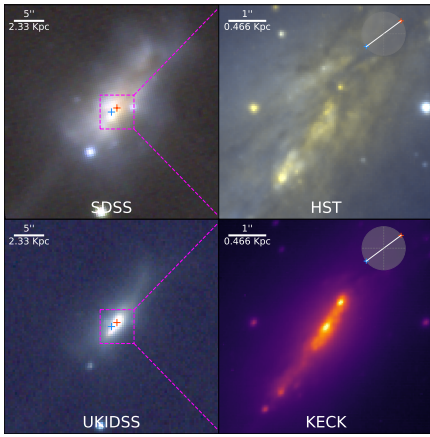


Figure C14. The images provided above are described at the beginning of Appendix C. Note that this target does not have a UKIDSS Y-band cutout image available, thus the UKIDSS three-color image is comprised of *K*-band, *H*-band, and *J*-band images.

composite classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

C.14. J132035+340822

J132035 is one of the targets in the Primary Keck AO Merger Sample that has publicly available NIRC2 imaging in the Keck archive (see Section 3.4). Keck LGSAO observations of this target were conducted with the NIRC2 Wide-Field Camera (FOV: $40'' \times 40''$; pixel scale: $0.039686 \text{ pixel}^{-1}$) in the K_s ($\lambda_c = 2.146 \mu\text{m}$) filter as part of Keck observing program Z229 in 2017. Additionally, this target was included in the GOALS HST sample (L. Armus et al. 2009), where it was imaged with ACS/WFC using the F435W and F814W filters (GO program 10592; PI: A. Evans). The SDSS and UKIDSS imaging of this target shows it is a highly disturbed late-stage merger with a bright and elongated central nucleus. An extended tidal tail stretching toward the northwest is visible in both the optical and IR. Additionally, outside the FOV of the SDSS image, there are two perpendicular tidal tails, one extending 23 kpc to the southeast and the other 29 kpc to the southwest. NIRC2 imaging of J132035 reveals dual nuclei separated by 0.784 or 0.365 kpc and a PA of 329.747° . C. Romero-Cañizales et al. (2017) confirmed the AGN nature of the central nucleus in J132035, reporting the presence of a parsec-scale jet based on high-resolution VLBI observations. The secondary nucleus located to the northwest of the central nucleus has not been confirmed as an AGN. The SDSS/WISE offset detected in the nucleus of J132035 has a separation of 1.209 and a PA of 306.487° , which overpredicts the separation of the dual nuclei but has a similar orientation. The high-resolution optical HST imaging of J132035 shows that both nuclei are heavily obscured by a large dust lane visible in the SDSS image and reveals an additional bright source of optical emission in the southeast of the HST image. It is likely that the partial obscuration of the nuclear region in J132035 is driving the SDSS/WISE offset we detect. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

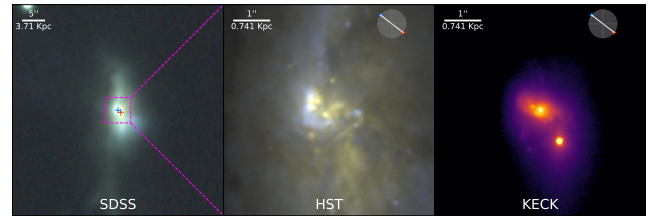


Figure C15. The images provided above are described at the beginning of Appendix C.

C.15. J134442+555313

J134442 is one of the targets in the Primary Keck AO Merger Sample that has publicly available NIRC2 imaging in the Keck archive (see Section 3.4). This target is a ULIRG and late-stage merger system with a very extended optical tidal tail stretching 40 kpc to the south in the SDSS image. V. U et al. (2013) conducted Keck LGSAO observations of this target with the NIRC2 Narrow-Field Camera (FOV: $10'' \times 10''$; pixel scale: $0.009942 \text{ pixel}^{-1}$) in the H ($\lambda_c = 1.633 \mu\text{m}$) and K_p filters. Here, we show the K_p filter image, which reveals two nuclei: a nucleus surrounded by a rotating gaseous disk in the northeast and a prominent nucleus in the southwest at a separation of 1.035 or 0.767 kpc and a PA of 211.969° . J134442 was confirmed to be a dual-AGN system by K. Iwasawa et al. (2018), with follow-up NuSTAR observations that are best explained by a dual-AGN system. Additionally, this target was included in the GOALS HST sample (L. Armus et al. 2009), where it was imaged with ACS/WFC using the F435W and F814W filters (GO program 10592; PI: A. Evans). The optical HST imaging of J134442 shows a much more disturbed morphology and significant obscuration, with the northeast AGN appearing partially obscured and the southwest AGN being completely obscured. The SDSS/WISE offset detected in this system roughly traces the separation and orientation of the dual-AGN system with a separation of 0.799 and a PA of 232.468° (i.e., $\Delta\text{Sep.} = 0.236$ and $\Delta\text{PA} = 20.499^\circ$). Due to the relative orientation of the SDSS/WISE offset, we can see that the WISE coordinate likely coincides with the obscured southwestern AGN and the SDSS with the northeastern AGN, showing that the SDSS/WISE offset is likely caused by the obscuration of the optical emission of the southwestern AGN. Additionally, due to the partial obscuration of the optical emission from the northeastern AGN, it is likely that the SDSS coordinate is not accurate to the position of the AGN and is thus causing the discrepancy between the PA of the SDSS/WISE offset and dual-AGN system. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color-color diagram.

C.16. J134651+371231

J134651 appears to be a postmerger system with an extended tidal tail extending 5.5 or 19.19 kpc to the northeast. The NIRC2 imaging reveals substructure in the form of apparent spiral arms in the northeast and southwest. In the northeast arm, we identify concentrated emission as the brightest secondary source of emission, forming a substructure pair with the central primary central nucleus with a separation

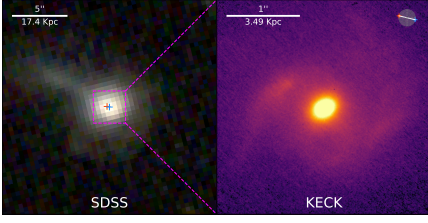


Figure C16. The images provided above are described at the beginning of Appendix C.

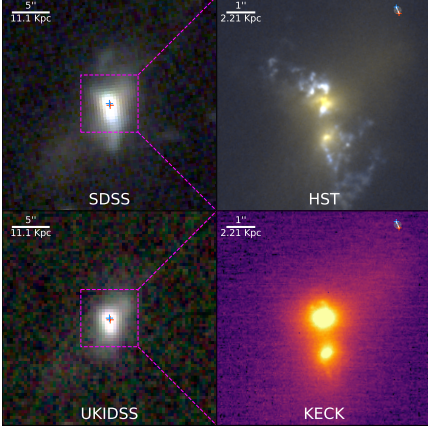


Figure C17. The images provided above are described at the beginning of Appendix C.

of $0''.633$ or 2.209 kpc and a PA of 63.589 . The SDSS/WISE offset detected in this system has a separation of $0''.230$ and a PA of 76.457 , which underpredicts the separation of the substructure, as expected (see Section 4.4), but appears accurate to the orientation of the spiral arm relative to the central nucleus. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

C.17. J135646+102608

J135646 is one of the targets in the Primary Keck AO Merger Sample that has publicly available NIRC2 imaging in the Keck archive (see Section 3.4). H. Fu et al. (2011a) conducted Keck LGSAO observations of this target with the NIRC2 Wide-Field Camera (FOV: $40'' \times 40''$; pixel scale: $0''.039686$ pixel $^{-1}$) in the K_p filter, as part of an observing program searching for kiloparsec-scale dual AGNs in double-peaked [O III] AGNs. Additionally, this target was included in the HST F438W and F814W observations of AGNs with double-peaked narrow emission lines presented in J. M. Comerford et al. (2015), where they identify J135646 as a candidate dual AGN. J135646 exhibits bipolar extended emission stretching ~ 15 kpc to the north and ~ 12 kpc to the south in SDSS but not in UKIDSS. Closer observations of this extended emission have found that it is likely to be a ~ 20 kpc scale outflow being driven by radiative feedback from an AGN in J135646 (e.g., J. E. Greene et al. 2012). The NIRC2 imaging of this target reveals a very bright northern nucleus and a dimmer southern nucleus forming a clear nuclear pair at a separation of $1''.253$ or 2.771 kpc and a PA of 185.403 . The HST imaging of J135646 similarly shows two

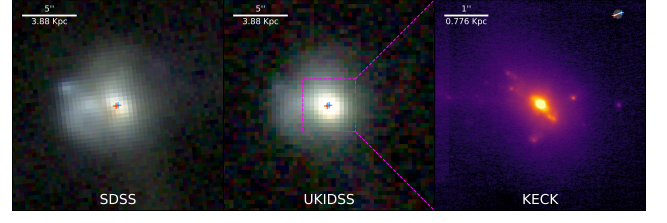


Figure C18. The images provided above are described at the beginning of Appendix C.

nuclei, although the optical emission of both nuclei is significantly broken up and distorted by the outflow identified by J. E. Greene et al. (2012). The SDSS/WISE offset detected in this system has a separation of $0''.258$ and a PA of 203.430 , which is not accurate to the orientation of the dual nuclei we see in the NIRC2 and HST imaging. Based on the location of the SDSS and WISE coordinates in the SDSS and UKIDSS cutout images, it is likely that the offset corresponds to the immediate vicinity of the northern nucleus. Assuming this, it is likely that the SDSS/WISE offset is tracing the complex optical emission of the outflow near the northern nucleus, with the WISE coordinate corresponding to the nucleus and the SDSS coordinate corresponding to the outflow. The host galaxy of this object is optically classified as a K_{01} -type AGN in the MPA-JHU catalog. Additionally, it lies within the AGN classification of our BPT diagram and within the Jarrett AGN region of our WISE color-color diagram.

C.18. J150517+080912

J1505 is a late-stage merger system with significant tidal features and an elongated nucleus. In its SDSS image, we see two tidal tails: one extending southward out to 11 kpc, and a western tail curving northward with an approximate length of 13 kpc. Additionally, there is a highly curved tail of emission coming out of the western side of the nucleus looping back into the galaxy toward the south, and another curved tail coming out of the northern side of the nucleus. The NIRC2 image of this target shows multiple sources of secondary emission at subarcsecond separations from the central primary nucleus. The brightest of the secondaries lies at a separation of $0''.347$ or 0.269 kpc and a PA of 218.893 , southeast from the primary nucleus. The SDSS/WISE offset separation and PA are $0''.194$ and 290.978 , which do not appear to be significantly correlated to the orientation of the substructure pair. There is a dimmer secondary in the image, which is separated from the primary nucleus by $0''.797$ and has a PA of 282.239 , which appears to be more consistent with the offset orientation. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

C.19. J151806+424444

J151806 is an extensively studied target also known as VV 705. The SDSS image shows that this is clearly a merging system that appears to have gone through its first pass, indicated by its very prominent tidal tails and bridge of emission between the two galaxies. This is a previously identified candidate dual AGN at a separation of 5.8 kpc, based on the detection of X-ray emission in both nuclei

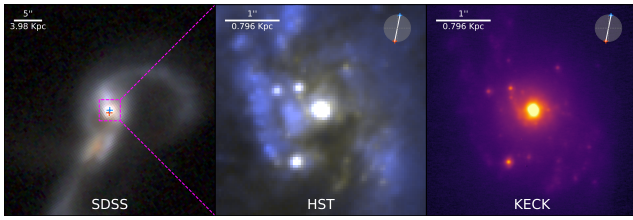


Figure C19. The images provided above are described at the beginning of Appendix C.

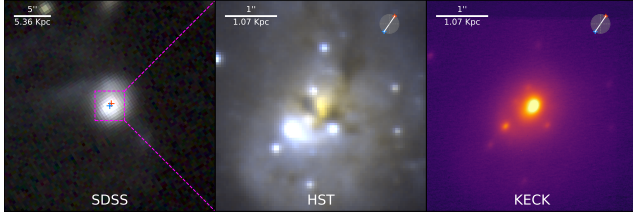


Figure C20. The images provided above are described at the beginning of Appendix C.

(see J. M. Comerford et al. 2022; L. He et al. 2023). This target is also included in the GOALS HST sample (L. Armus et al. 2009), where it was imaged with ACS/WFC using the F435W and F814W filters (GO program 10592; PI: A. Evans). With our NIRC2 imaging, we target the northwest galaxy, in which we detect an SDSS/WISE offset with a separation of $0''.500$ and a PA of 168.679 . In the high-resolution NIRC2 imaging of this target, we see a bright central primary nucleus and four additional secondary sources of emission in the immediate nuclear region of the galaxy. Of the four secondaries, the brightest lies $1''.083$ or 0.863 kpc in the southeast from the primary, with a PA of 156.010 . Together with the central primary nucleus, this forms the substructure pair in J151806. In the HST images of this target, we can see significant obscuration throughout the host galaxy, but the same substructure can still be seen in the optical. The PA of the substructure pair is very similar to that of the SDSS/WISE offset, suggesting that the detected offset is accurately tracing the substructure in this system. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram and outside the Jarrett AGN region of our WISE color-color diagram.

C.20. J152659+355837

J152659 is an advanced merger system with tidal tails in the southwest and east connected by an arc of emission with an approximate radius of $12''$ or 13 kpc. In the NIRC2 image, we can see multiple sources of substructure within the nuclear region of this target that were unresolved in SDSS. There is a prominent bright primary nucleus in the center of the galaxy, and we identify nine different secondary sources of NIR emission. The brightest of these secondaries lies $0''.631$ or 0.677 kpc away from the primary nucleus, with a PA of 127.543 . The SDSS/WISE offset that we detect in this system has a separation of $0''.376$ and a PA of 145.649 , which is relatively similar to the orientation of the substructure pair. J152659 has been studied extensively in the past at multiple wavelengths and lower resolutions, with some identifying the same substructure seen in the NIRC2 image. N. Z. Scoville

et al. (2000) present HST NICMOS imaging of this galaxy at $1.1 \mu\text{m}$, $1.6 \mu\text{m}$, and $2.2 \mu\text{m}$ and identify the same pair of candidate nuclei. N. Z. Scoville et al. (2000) do not classify the secondary source as a nucleus or SF region, though it is noted that the NIR colors of the secondary source are very red. Additionally, this target was included in the GOALS HST sample (L. Armus et al. 2009), where it was imaged with ACS/WFC using the F435W and F814W filters (GO program 10592; PI: A. Evans). The same sources of secondary NIR emission can be seen in the optical HST imaging, except for the primary central nucleus, where it is significantly obscured. When analyzed in conjunction with the orientation of the SDSS/WISE offset, it appears that the WISE coordinate traces the location of the primary nucleus and the SDSS coordinate the unobscured secondary. The host galaxy of this object is optically classified as a K_{03} -type AGN in the MPA-JHU catalog. Additionally, it lies within the composite classification of our BPT diagram but is not included in the WISE color-color diagram, due to it not having a listed W_3 magnitude.

ORCID iDs

Camilo Vazquez <https://orcid.org/0000-0002-2121-8426>
 S. Satyapal <https://orcid.org/0000-0003-2277-2354>
 G. Canalizo <https://orcid.org/0000-0003-4693-6157>
 N. J. Secrest <https://orcid.org/0000-0002-4902-8077>
 R. W. Pfeifle <https://orcid.org/0000-0001-8640-8522>
 T. Bohn <https://orcid.org/0000-0002-4375-254X>
 K. Nyland <https://orcid.org/0000-0003-1991-370X>
 A. Aravindan <https://orcid.org/0000-0001-7578-2412>
 L. Blecha <https://orcid.org/0000-0002-2183-1087>
 Jenna M. Cann <https://orcid.org/0000-0003-1051-6564>
 S. Doan <https://orcid.org/0000-0003-3152-4328>
 E. K. S. Hicks <https://orcid.org/0000-0002-4457-5733>
 P. Kurczynski <https://orcid.org/0000-0002-8816-5146>
 S. Juneau <https://orcid.org/0000-0002-0000-2394>
 M. Malkan <https://orcid.org/0000-0001-6919-1237>
 J. McKaig <https://orcid.org/0000-0002-0913-3729>
 P. Nair <https://orcid.org/0000-0001-7069-4026>
 B. Rothberg <https://orcid.org/0000-0003-2283-2185>
 F. Muller-Sanchez <https://orcid.org/0000-0002-2713-0628>
 E. Schwartzman <https://orcid.org/0000-0002-6454-861X>
 R. Sexton <https://orcid.org/0000-0003-3432-2094>
 V. U <https://orcid.org/0000-0002-1912-0024>

References

- Abazajian, K. N., Adelman-McCarthy, J. K., Agüeros, M. A., et al. 2009, *ApJS*, **182**, 543
- Agazie, G., Anumalapudi, A., Archibald, A. M., et al. 2023, *ApJL*, **951**, L8
- Amaro-Seoane, P., Audley, H., Babak, S., et al. 2017, arXiv:1702.00786
- Armus, L., Mazzarella, J. M., Evans, A. S., et al. 2009, *PASP*, **121**, 559
- Assef, R. J., Stern, D., Kochanek, C. S., et al. 2013, *ApJ*, **772**, 26
- Assef, R. J., Stern, D., Noirod, G., et al. 2018, *ApJS*, **234**, 23
- Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., et al. 2022, *ApJ*, **935**, 167
- Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., et al. 2018, *AJ*, **156**, 123
- Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, *A&A*, **558**, A33
- Baldwin, J. A., Phillips, M. M., & Terlevich, R. 1981, *PASP*, **93**, 5
- Bianchi, S., Chiaberge, M., Piconcelli, E., Guainazzi, M., & Matt, G. 2008, *MNRAS*, **386**, 105
- Blecha, L., Snyder, G. F., Satyapal, S., & Ellison, S. L. 2018, *MNRAS*, **478**, 3056
- Borne, K. D., Bushouse, H., Colina, L., et al. 1999, *ASPC*, **177**, 167
- Brinchmann, J., Charlot, S., White, S. D. M., et al. 2004, *MNRAS*, **351**, 1151

- Capelo, P. R., Dotti, M., Volonteri, M., et al. 2017, *MNRAS*, **469**, 4437
- Capelo, P. R., Volonteri, M., Dotti, M., et al. 2015, *MNRAS*, **447**, 2123
- Casali, M., Adamson, A., Alves de Oliveira, C., et al. 2007, *A&A*, **467**, 777
- Chen, N., Di Matteo, T., Ni, Y., et al. 2023a, *MNRAS*, **522**, 1895
- Chen, Y.-C., Hwang, H.-C., Shen, Y., et al. 2022, *ApJ*, **925**, 162
- Chen, Y.-C., Liu, X., Lazio, J., et al. 2023b, *ApJ*, **958**, 29
- Colpi, M., Danzmann, K., Hewitson, M., et al. 2024, arXiv:2402.07571
- Comerford, J. M., Negus, J., Barrows, R. S., et al. 2022, *ApJ*, **927**, 23
- Comerford, J. M., Nevin, R., Stemo, A., et al. 2018, *ApJ*, **867**, 66
- Comerford, J. M., Pooley, D., Barrows, R. S., et al. 2015, *ApJ*, **806**, 219
- Comerford, J. M., Pooley, D., Gerke, B. F., & Madejski, G. M. 2011, *ApJL*, **737**, L19
- Comerford, J. M., Schluns, K., Greene, J. E., & Cool, R. J. 2013, *ApJ*, **777**, 64
- Conselice, C. J. 2006, *ApJ*, **638**, 686
- Darg, D. W., Kaviraj, S., Lintott, C. J., et al. 2010, *MNRAS*, **401**, 1043
- De Rosa, A., Vignali, C., Bogdanović, T., et al. 2019, *NewAR*, **86**, 101525
- Fritz, T., Gillessen, S., Trippe, S., et al. 2010, *MNRAS*, **401**, 1177
- Fu, H., Myers, A. D., Djorgovski, S. G., & Yan, L. 2011a, *ApJ*, **733**, 103
- Fu, H., Yan, L., Myers, A. D., et al. 2012, *ApJ*, **745**, 67
- Fu, H., Zhang, Z.-Y., Assef, R. J., et al. 2011b, *ApJL*, **740**, L44
- Ge, J.-Q., Hu, C., Wang, J.-M., Bai, J.-M., & Zhang, S. 2012, *ApJS*, **201**, 31
- Greene, J. E., Zakamska, N. L., & Smith, P. S. 2012, *ApJ*, **746**, 86
- Haan, S., Surace, J. A., Armus, L., et al. 2011, *AJ*, **141**, 100
- Hambly, N. C., Collins, R. S., Cross, N. J. G., et al. 2008, *MNRAS*, **384**, 637
- Harris, C. R., Millman, K. J., van der Walt, S. J., et al. 2020, *Natur*, **585**, 357
- He, L., Hou, M., Li, Z., Feng, S., & Liu, X. 2023, *ApJ*, **949**, 49
- Hernández-Toledo, H. M., Avila-Reese, V., Conselice, C. J., & Puerari, I. 2005, *AJ*, **129**, 682
- Hewett, P. C., Warren, S. J., Leggett, S. K., & Hodgkin, S. T. 2006, *MNRAS*, **367**, 454
- Hopkins, P. F., & Hernquist, L. 2006, *ApJS*, **166**, 1
- Hou, M., Liu, X., Guo, H., et al. 2019, *ApJ*, **882**, 41
- Hunt, L. K., & Malkan, M. A. 2004, *ApJ*, **616**, 707
- Hwang, H.-C., Shen, Y., Zakamska, N., & Liu, X. 2020, *ApJ*, **888**, 73
- Irwin, M. J. 2008, in 2007 ESO Instrument Calibration Workshop, ed. A. Kaufer & F. Kerber (ESO), 541
- Iwasawa, K., U, V., Mazzarella, J. M., et al. 2018, *A&A*, **611**, A71
- Jarrett, T. H., Cohen, M., Masci, F., et al. 2011, *ApJ*, **735**, 112
- Kauffmann, G., Heckman, T. M., Tremonti, C., et al. 2003b, *MNRAS*, **346**, 1055
- Kauffmann, G., Heckman, T. M., White, S. D. M., et al. 2003a, *MNRAS*, **341**, 33
- Kelley, L. Z., Blecha, L., & Hernquist, L. 2017, *MNRAS*, **464**, 3131
- Kewley, L. J., Dopita, M. A., Sutherland, R. S., Heisler, C. A., & Trevena, J. 2001, *ApJ*, **556**, 121
- Kim, D. C., Yoon, I., Evans, A. S., et al. 2020, *ApJ*, **904**, 23
- Kim, M., Barth, A. J., Ho, L. C., & Son, S. 2021, *ApJS*, **256**, 40
- King, I. R. 1983, *PASP*, **95**, 163
- Komossa, S., Burwitz, V., Hasinger, G., et al. 2003, *ApJL*, **582**, L15
- Koss, M., Mushotzky, R., Treister, E., et al. 2012, *ApJL*, **746**, L22
- Koss, M. J., Blecha, L., Bernhard, P., et al. 2018, *Natur*, **563**, 214
- Koss, M. J., Treister, E., Kakkad, D., et al. 2023, *ApJL*, **942**, L24
- Lawrence, A., Warren, S. J., Almaini, O., et al. 2007, *MNRAS*, **379**, 1599
- Li, K., Ballantyne, D. R., & Bogdanović, T. 2021, *ApJ*, **916**, 110
- Li, K., Bogdanović, T., Ballantyne, D. R., & Bonetti, M. 2022, *ApJ*, **933**, 104
- Lintott, C. J., Schawinski, K., Slosar, A., et al. 2008, *MNRAS*, **389**, 1179
- Liu, X., Civano, F., Shen, Y., et al. 2013, *ApJ*, **762**, 110
- Liu, X., Greene, J. E., Shen, Y., & Strauss, M. A. 2010a, *ApJL*, **715**, L30
- Liu, X., Shen, Y., Strauss, M. A., & Greene, J. E. 2010b, *ApJ*, **708**, 427
- Lyu, Y., & Liu, X. 2016, *MNRAS*, **463**, 24
- Malkan, M. A., Gorjian, V., & Tam, R. 1998, *ApJS*, **117**, 25
- Mannucci, F., Scialpi, M., Ciurlo, A., et al. 2023, *A&A*, **680**, A53
- Marocco, F., Eisenhardt, P. R. M., Fowler, J. W., et al. 2021, *ApJS*, **253**, 8
- Maschmann, D., Melchior, A.-L., Mamon, G. A., Chilingarian, I. V., & Katkov, I. Y. 2020, *A&A*, **641**, A171
- McGurk, R. C., Max, C. E., Medling, A. M., Shields, G. A., & Comerford, J. M. 2015, *ApJ*, **811**, 14
- Merritt, D., & Milosavljević, M. 2005, *LRR*, **8**, 8
- Müller-Sánchez, F., Comerford, J. M., Nevin, R., et al. 2015, *ApJ*, **813**, 103
- Pfeifle, R. W., Satyapal, S., Manzano-King, C., et al. 2019a, *ApJ*, **883**, 167
- Pfeifle, R. W., Satyapal, S., Secrest, N. J., et al. 2019b, *ApJ*, **875**, 117
- Pfeifle, R. W., Weaver, K. A., Secrest, N. J., Rothberg, B., & Patton, D. R. 2025, *ApJS*, **281**, 25
- Pierce, J. C. S., Tadhunter, C., Ramos Almeida, C., et al. 2023, *MNRAS*, **522**, 1736
- Ricci, C., Bauer, F. E., Treister, E., et al. 2017, *MNRAS*, **468**, 1273
- Romero-Cañizales, C., Alberdi, A., Ricci, C., et al. 2017, *MNRAS*, **467**, 2504
- Rosario, D. J., Shields, G. A., Taylor, G. B., Salvander, S., & Smith, K. L. 2010, *ApJ*, **716**, 131
- Satyapal, S., Ellison, S. L., McAlpine, W., et al. 2014, *MNRAS*, **441**, 1297
- Satyapal, S., Secrest, N. J., Ricci, C., et al. 2017, *ApJ*, **848**, 126
- Schwartzman, E., Clarke, T. E., Nyland, K., et al. 2024, *ApJ*, **961**, 233
- Scoville, N. Z., Evans, A. S., Thompson, R., et al. 2000, *AJ*, **119**, 991
- Service, M., Lu, J. R., Campbell, R., et al. 2016, *PASP*, **128**, 095004
- Shen, Y., Hwang, H.-C., Zakamska, N., & Liu, X. 2019, *ApJL*, **885**, L4
- Shen, Y., Liu, X., Loeb, A., & Tremaine, S. 2013, *ApJ*, **775**, 49
- Smith, K. L., Shields, G. A., Bonning, E. W., et al. 2010, *ApJ*, **716**, 866
- Snyder, G. F., Hayward, C. C., Sajina, A., et al. 2013, *ApJ*, **768**, 168
- Stern, D., Assef, R. J., Benford, D. J., et al. 2012, *ApJ*, **753**, 30
- Taylor, M. B. 2005, *ASPC*, **347**, 29
- Toomre, A., & Toomre, J. 1972, *ApJ*, **178**, 623
- Treister, E., Privon, G. C., Sartori, L. F., et al. 2018, *ApJ*, **854**, 83
- Tremonti, C. A., Heckman, T. M., Kauffmann, G., et al. 2004, *ApJ*, **613**, 898
- Troncoso, M., Treister, E., Rojas, A., et al. 2025, *ApJ*, **994**, 181
- U, V., Medling, A., Sanders, D., et al. 2013, *ApJ*, **775**, 115
- Uppal, A., Ward, C., Gezari, S., et al. 2024, *ApJ*, **975**, 286
- Vakili, M., & Hogg, D. W. 2016, arXiv:1610.05873
- van Dam, M. A., Bouchez, A. H., Le Mignant, D., et al. 2006, *PASP*, **118**, 310
- Van Wassenhove, S., Volonteri, M., Mayer, L., et al. 2012, *ApJL*, **748**, L7
- Virtanen, P., Gommers, R., Oliphant, T. E., et al. 2020, *NatMe*, **17**, 261
- Voggel, K. T., Seth, A. C., Baumgardt, H., et al. 2022, *A&A*, **658**, A152
- Wang, H.-C., Wang, J.-X., Gu, M.-F., & Liao, M. 2023, *MNRAS*, **524**, L38
- Wang, J.-M., Chen, Y.-M., Hu, C., et al. 2009, *ApJL*, **705**, L76
- Wizinowich, P., Acton, D. S., Shelton, C., et al. 2000, *PASP*, **112**, 315
- Wizinowich, P. L., Le Mignant, D., Bouchez, A. H., et al. 2006, *PASP*, **118**, 297
- Wright, E. L., Eisenhardt, P. R. M., Mainzer, A. K., et al. 2010, *AJ*, **140**, 1868
- Zhao, D., Ho, L. C., Zhao, Y., Shanguan, J., & Kim, M. 2019, *ApJ*, **877**, 52