A Systematic Search for Dual Active Galactic Nuclei in Merging Galaxies (ASTRO-DARING) II: First Results from Long-slit Spectroscopic Observations

Yang-Wei Zhang1,3, Yang Huang2,5, Jin-Ming Bai1,4,5, Xiao-Wei Liu2,5, Jian-guo Wang1, and Xiao-bo Dong1

1 Yunnan Observatories, Chinese Academy of Sciences, Kunming, Yunnan 650011, People’s Republic of China; yangweizhang@ynao.ac.cn, x.liu@ynu.edu.cn
2 South-Western Institute for Astronomy Research, Yunnan University, Kunming 650500, People’s Republic of China; yanghuang@ynu.edu.cn, x.liu@ynu.edu.cn
3 University of Chinese Academy of Sciences, Beijing 100049, People’s Republic of China
4 Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650011, People’s Republic of China

Abstract

Building a large sample of kiloparsec (kpc)-scale dual active galactic nuclei (AGNs) among merging galaxies is of vital importance to understand the coevolution between host galaxies and their central supermassive black holes (SMBHs). Doing so, with just such a sample, we have developed an innovative method of systematically searching and identifying dual AGNs among kpc-scale merging galaxies and selected 222 candidates at redshifts $z < 0.25$. All the selected candidates have radio detection in the Faint Images of the Radio Sky at Twenty Centimeters survey and at least one of two cores previously revealed as AGN spectroscopically. We report the first results from a systematic search for dual AGNs in merging galaxies (ASTRO-DARING), which consist of spatially resolved long-slit spectroscopic observations of 41 targets selected from our merging galaxies sample carried out between 2014 November and 2017 February, using the Yunnan Faint Object Spectrograph and Camera mounted on the 2.4 meter telescope in Lijiang of Yunnan Observatories. Of these, 16 are likely dual AGNs, and 15 are newly identified. The efficiency of ASTRO-DARING is thus nearly 40%. With this method, we plan to build the first even sample of more than 50 dual AGNs constructed using a consistent approach. Further analysis of the dual AGN sample shall provide vital clues for understanding the coevolution of galaxies and SMBHs.

Unified Astronomy Thesaurus concepts: Active galactic nuclei (16); Galaxy mergers (608); Galaxy spectroscopy (2171); Interacting galaxies (802)

1. Introduction

Galaxy merging plays an vital role for galaxy growth in the standard ΛCDM cosmology (e.g., Kauffmann & Haehnelt 2000; Di Matteo et al. 2005; Kormendy & Ho 2013). As essentially all massive galaxies are believed to host a central supermassive black hole (SMBH; e.g., Kormendy & Richstone 1995; Richstone et al. 1998), one expects to find SMBH pairs in merging galaxies (e.g., Begelman et al. 1980; Milosavljević & Merritt 2001). The merging would also trigger active galactic nuclei (AGNs) activities when large amounts of gas fall into the central SMBHs via gravitational interactions (e.g., Hopkins et al. 2008; Kocevski et al. 2012; Treister et al. 2012). In this scenario, dual AGNs are expected to form in merging galaxies (e.g., Koss et al. 2012; Satyapal et al. 2017). For merging galaxies of projected separations smaller than 15 kpc (typical tidal radius of a galaxy), the gravitational interactions between the two merging galaxies become significant (e.g., Begelman et al. 1980; Volonteri et al. 2003). Identifying dual AGNs at this critical stage before final coalescence among gas-rich merging galaxies can provide vital information to investigate the coevolution of SMBHs and their host galaxies (e.g., Colpi & Dotti 2011; Yu et al. 2011), for example, the underlying physics of the tight scaling relations between the black hole (BH) mass ($M_{\rm BH}$) and large-scale properties of the host galaxy found from observations, especially the well-known relation between central BH mass and host galaxy bulge velocity dispersion ($\sigma$; e.g., Ferrarese & Merritt 2000; Gebhardt et al. 2000; Häring & Rix 2004; Gültekin et al. 2009; Graham & Scott 2013; Kormendy & Ho 2013; McConnell & Ma 2013). While considered fundamental and supported by bona fide observational evidence, it is still not clear whether the $M_{\rm BH}-\sigma$ relation is universal and followed by all types of galaxies including merging galaxies (e.g., Komossa & Xu 2007; Fu et al. 2011a; Savorgnan & Graham 2015). Previous studies indicate that dual AGN systems may not follow the typical $M_{\rm BH}-\sigma$ relation defined from isolated AGNs and thus can contribute scatter to this relation (e.g., Blecha et al. 2011; Fu et al. 2011a). The physical mechanisms connecting the growth of BH mass and the host galaxy are also not well understood (e.g., Ricci et al. 2017; Sheinis and López-Sánchez 2017). Other questions related include how the phenomenon of dual AGNs is triggered and how they evolve in the merging progresses (e.g., Treister et al. 2012; Satyapal et al. 2017). Being the late-stage products of galaxy merging, dual AGNs can clearly help address these fundamental questions (e.g., Kosec et al. 2017; Solanes et al. 2019). To answer the above questions, a large sample of dual AGNs is required. However, the current number of identified dual AGNs is limited, with a total number of no more than 50 (see the compilation in Das et al. (2018) and Y. Huang et al. (2021, in preparation); hereafter Paper I). These confirmed dual AGNs are identified by a variety of methods, such as X-ray observations (e.g., Komossa et al. 2003; Guainazzi et al. 2005; Hudson et al. 2006; Comerford et al. 2011; Liu et al. 2013; Comerford et al. 2015; Koss et al. 2016; Ellison et al. 2017; Hou et al. 2019, 2020), radio observations (e.g., Rodriguez et al. 2006; Fu et al. 2011b, 2015; Müller-Sánchez et al. 2015; Rubin et al. 2017), and optical spectroscopy (e.g., Liu et al. 2010, 2011; Shen et al. 2011; Huang et al. 2014).

In the past decades, several systematic methods have been developed for identifying dual AGNs. One of the most ambitious methods is finding dual AGNs from double-peaked...
AGNs (DPAGNs). As a potential mechanism, binary/dual AGNs with projected separations ranging from 100 pc to 10 kpc could contribute DPAGNs (e.g., Zhou et al. 2004; Wang et al. 2009). Thanks to massive spectroscopic surveys, such as the Sloan Digital Sky Survey (SDSS) and DEEP2 Galaxy Survey, hundreds of DPAGNs have been spectroscopically selected (e.g., Gerke et al. 2007; Wang et al. 2009; Liu et al. 2010; Smith et al. 2010; Rosario et al. 2011; Ge et al. 2012; Barrows et al. 2013; Shi et al. 2014; McGurk et al. 2015). However, spatially resolved long-slit/integral-field spectroscopy (e.g., Liu et al. 2011; McGurk et al. 2011; Shen et al. 2011; Comerford et al. 2012) and high-resolution imaging (e.g., Liu et al. 2013; Comerford et al. 2015; Müller-Sánchez et al. 2015) follow-up observations show that only 2%–5% of DPAGNs are dual AGNs, and most of DPAGNs are produced by gas kinematics related to a single AGN (e.g., rotating gas disks or biconical outflows from the narrow-line region (NLR) of the AGN; Comerford et al. 2011; Smith et al. 2011, 2012; Shen et al. 2011; Fu et al. 2011a, 2012; Gabányi et al. 2014; Nevin et al. 2016). Most recently, the systematic search for dual AGNs based on radio imaging (Fu et al. 2015) and mid-infrared color (Satyapal et al. 2014, 2017) has been proposed but the number of identified dual AGNs is still very limited (see Section 4 for more details).

It is a challenging task to build a homogeneous dual AGN sample for the purpose of studying the coevolution of SMBHs and host galaxies. A more robust and efficient new method is clearly desirable. Inspired by previous studies (e.g., Hennawi et al. 2006, 2010; Ellison et al. 2011; Satyapal et al. 2014; Rubinur et al. 2019), we have developed an innovative method of systematically finding and identifying dual AGNs among kpc-scale merging galaxies (see Section 2.1 and Paper I for more details). With this new method, a total of 222 targeted candidates (merging galaxies) have been selected. To reveal their dual AGN nature, we have embarked on an observational campaign, a systematic search for dual AGNs in merging galaxies (ASTRO-DARING for short), using spatially resolved long-slit and aperture spectroscopy.

In this work (hereafter Paper II), we present the first results of ASTRO-DARING from 2014 November to 2017 February using the Yunnan Faint Object Spectrograph and Camera (YFOSC) mounted on the 2.4 m telescope in Lijiang (JLT) of the Yunnan Observatories (YNAO). The observation and data reduction are described in Section 2. The results are presented in Section 3. In Section 4, we discuss the implications and potential applications of our current results. Finally, a summary is given in Section 5. Cosmological constants $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$ are adopted throughout the paper, and all wavelengths are vacuum.

2. Observation and Data Reduction

2.1. Sample Selection

As mentioned above, ASTRO-DARING proposes an efficient method of searching for and identifying dual AGNs among merging galaxies. To do so, we first select galaxies that are potentially undergoing a merging process from the SDSS photometric catalog from DR9 (Ahn et al. 2012): galaxies exhibiting two optical cores separated by less than 8″ and at least one optical core with SDSS fiber spectra from DR12/14 (Alam et al. 2015; Abolfathi et al. 2018). Second, the candidates are selected with at least one radio detection from the Faint Images of the Radio Sky at Twenty Centimeters (FIRST) survey (Helfand et al. 2015) in order to exclude physically unrelated pairs as merging galaxies. Typically, enhanced radio radiation is expected from merge-driven star formations or starbursts (e.g., Sanders et al. 1988; Bell et al. 2006; Jogee et al. 2009; Robaina et al. 2009). Based on this, the requirement of radio detection can help remove the physically unrelated pairs from the merging galaxies to a certain extent. Finally, only systems with at least one core previously identified as an AGN with redshift $z < 0.25$ by analyzing the SDSS DR12/14 spectra (Páris et al. 2017, 2018) are selected as dual AGN candidates. In this manner, a total of 222 dual AGN candidates ($z < 0.25$) are selected among the merging galaxies sample from the SDSS catalog. We note that the current sample has a rough limiting magnitude of $i$ band model magnitude $\sim 19.5–20$ due to the redshift cut ($z < 0.25$), and the sample will miss dual AGN systems with radio radiation below the FIRST detection threshold (i.e., 1 mJy). More details about sample selection are provided in Paper I.

2.2. Observations

To identify the candidates as real dual AGNs, we have carried out the ASTRO-DARING campaign to collect spatially resolved long-slit spectroscopic observations of the candidates. The 2D spatially resolved long-slit spectra allow one to explore the activity nature of the two cores in the merging system (e.g., Shen et al. 2011) and thus help us diagnose whether the observed target is a real dual AGN or not. The long-slit spectra are required to cover the emission lines of H$_\beta$, [O III] $\lambda\lambda$5007, [O I] $\lambda$6300, H$_\alpha$, [N II] $\lambda\lambda$6549,6583, and [S II] $\lambda\lambda$6717,6731 in the optical band with resolving power of $R > 300$ (corresponding to a velocity resolution $> 1000$ km s$^{-1}$), thus enabling us to identify AGNs by either measuring the FWHM of the Balmer emission lines or using the classical Baldwin–Phillips–Terlevich (BPT; Baldwin et al. 1981) diagrams with emission line ratios.

All spectroscopic observations reported here were obtained with the YFOSC mounted on the LJT of the YNAO as part of the ASTRO-DARING campaign. YFOSC is a multimode instrument for both imaging and low/medium resolution spectroscopy, working at the Cassegrain focus (Fan et al. 2015). The CCD sensor is a 2k $\times$ 4k back-illuminated deep depletion chip, with a pixel size of 13.5 $\mu$m that projects to 0″283 per pixel on the sky, covering a field of view of about $9.6 \times 9.6$ square arcmin.

Several grisms of different spectral resolutions and wavelength ranges are available for YFOSC. The spectrograph can be used in long-slit mode with several slits of different widths available. We note the overall sensitivity of the grisms (including the telescope and detectors) are about 10%–20% and even >5% at the blue beginning and red end. For each candidate, the two optical cores are spatially resolved in the SDSS images, and the slit is set to pass through the two cores of the merging galaxies. For this purpose, the spectrograph is rotated with a specific position angle (PA) for each galaxy pair.

---

5 Both cores are classified as galaxies in SDSS DR9 (Ahn et al. 2012).

7 The FIRST survey has already released the final catalog (Helfand et al. 2015) and presented definitive high-resolution 20 cm maps covering a total sky area of 10,575 deg$^2$ at 1.4 GHz, using the Very Large Array (VLA) with a detection sensitivity of 1 mJy.

8 The wavelengths of the adopted grisms are present in Table 1.
and the values of PA for the individual systems are presented in Table 2. In this way, we obtain 2D spatially resolved spectra for the two cores in the merging systems, under good seeing conditions.

The ASTRO-DARING project was started in 2014 November. All observations presented here were carried out with the YFOSC in long-slit mode using several slits of fixed widths, depending on the observing conditions, especially the seeing and transparency. Depending on the grisms used, our observations can be divided into two phases. The first phase is from 2014 November to 2015 November. During this period, we mainly used two grisms: a blue one G14 covering 3600–7500 Å and a red one G8 covering 5100–9600 Å. A slit of width 1.8 matching the typical seeing was used during this phase. With the above combinations, the typical resolutions are about 330 ± 20 km s\(^{-1}\) and 500 ± 40 km s\(^{-1}\) for the G8 and G14 grisms, respectively (Table 1). In total, 15 targets were observed during this period.

Due to the increasing seeing and decreasing transparency (possibly caused by El Niño effects\(^9\)), we changed to using G3 that has a higher efficiency than G14 and G8 but a lower resolution in the second phase (from 2015 November–2017 February). The spectra obtained cover the whole optical wavelength range (3400–9100 Å).\(^10\) Depending on the seeing condition, a slit of width 1.8 or 2.5 was adopted. The resulting spectral resolution was relatively low with FWHMs of 730 ± 60 km s\(^{-1}\) and 970 ± 70 km s\(^{-1}\), respectively, for the 1.8 and 2.5 slits of the G3 grism. In this phase, a total of 26 targets were observed.

Totally, we obtained long-slit spectra for 41 candidates between 2014 November and 2017 February using the YFOSC. For more details, see the observational log in Table 2.

### Table 1

| Grism | Spectral range Å | Dispersion nm pix\(^{-1}\) | Resolution\(_{1,8}\) (km s\(^{-1}\)) | Resolution\(_{2,5}\) (km s\(^{-1}\)) |
|-------|------------------|-----------------------------|----------------------------------|----------------------------------|
| G8    | 5100–9600        | 0.15                        | 330 ± 20                         | –                                |
| G14   | 3600–7500        | 0.17                        | 500 ± 40                         | –                                |
| G3    | 3400–9100        | 0.29                        | 730 ± 60                         | 970 ± 70                         |

Note. Resolution\(_{1,8}\) median resolution of the instrumental broadening for a slit width of 1.8. Resolution\(_{2,5}\) median resolution of the instrumental broadening for a slit width of 2.5. The instrumental broadening was measured from the arc lamp spectra.

2.3. Data Reduction

#### 2.3.1. Wavelength and Flux Calibration

The data were reduced with the IRAF\(^{11}\) and IDL routines. The 2D spectra were bias subtracted, flat-fielded calibrated, with cosmic-rays fully removed (using the IRAF task crmedian), wavelength calibrated, and flux calibrated on 2D with IRAF. The wavelength and flux calibrations were applied to all 2D spectra. The wavelength distortions in the spatial direction were carefully corrected using a 2D wavelength map constructed by arc frame performed on IRAF. The ESO spectroscopic standard stars observed on the same night were applied to the flux calibrations. The sky background was subtracted in a 2D manner by the background implemented in IRAF. The above steps were all carried out with IRAF for the 2D spectra. After those, the IDL routine was adopted to extract the final 1D spectra. More details about this step are presented below.

2.3.2. Extraction of 1D Spectra

To explore the activity natures of the two cores in the merging system, 1D spectra of the two cores in the system are extracted from the spatially resolved 2D spectrum. When extracting the 1D spectra, flux loss and contamination are unavoidable as the spectra of the two cores are close to each other. We therefore developed a 1D extraction method by achieving a tradeoff between reducing flux loss and contamination.

An example of the 1D extraction is shown in Figure 1. The flux distribution along the spatial direction is contributed by the two galaxies/AGNs and the sky background residuals. We assumed that the contribution from each of the two nuclei can be represented by a Gaussian, while that of the residual sky background can be represented by a first-order polynomial accounting for any systematic pattern left in the subtracted background. To extract the spectrum of each galaxy/AGN, the flux distribution is fit by two Gaussians plus a first-order polynomial, and the 1D spectra of each two galaxy/AGN are obtained, as shown in the right panel of Figure 1. The inner/outer boundaries in Figure 1 are set when the 1D spectra of the two cores are extracted from the 2D spectrum. The outer boundary of each of the two galaxies/AGNs is defined as the position of the 2σ width from the center of the fitted Gaussian. This was chosen in order to enclose as much of the flux from the target but as possible with minimum noise from the background (see the two white dashed lines on the two sides of the galaxies/AGNs in the right panel of Figure 1). For the central overlapping region of the two galaxies/AGNs, the position of equal flux of the two fitted Gaussians is selected as the inner boundary to minimize the flux loss and contamination of each target (see the middle white dashed line in the right panel of Figure 1). Given the above extraction procedures, the true flux of one target is assumed by the total flux under the fitted Gaussian, and then the flux loss is given by the total area beyond the inner and outer boundaries of the fitted Gaussian. The flux contamination is defined as the total flux tail between the extracted inner and outer boundaries, extended from the nearby target (true flux also represented by another fitted Gaussian). We note that the extraction limits (the inner/outer boundaries) are for purposes of summing across the spatial dimension.

To account for the effects of possible slit tilt, the whole long-slit spectrum is divided into six slices along the wavelength direction, and the 1D spectra in each slice are extracted with the above procedure. Given the relatively large angular separations of our selected candidates, the spectra of the two cores in merging galaxies are well separated in general and their 1D

---

\(^9\) El Niño effects result from the rise of sea surface temperatures in the Indian Ocean. It may not bring drought but cause heavy rainfall at certain periods.

\(^10\) We note that the effect of second-order contamination at wavelengths smaller than 4550 Å is largely smaller than 5%–10%. Moreover, the current analysis is not affected by this issue since all of our concerned emission lines are longer than 4550 Å.

\(^11\) http://ast.noao.edu/data/software

\(^12\) The tilt angle of YFOSC slits are largely adjusted to 0.3–0.5 degrees, and thus the tilt changes are within 1–3 pixels along the whole slices (each with a length of about 300 pixels). In addition, six slices are enough to account for the point-spread function (PSF) along the wavelength direction (mostly within 1–2 pixels).
### Table 2
Observational Log

| Name    | R.A. (J2000) | Decl. (J2000) | Redshift | Sep0 (/kpc) | Sep1 (/kpc) | Grism | Slew width (") | Observing date | Seeing (") | PA (°) | Exposure time (s) |
|---------|--------------|--------------|----------|-------------|-------------|-------|----------------|----------------|-------------|--------|------------------|
|         | 01:51:07.74  | −02:45:27.66 | 0.0479   | 5.3/5.0     | 5.1/4.9     | G14   | 1.8            | 20141211       | 2.2         | 98.3  | 2500            |
| J0151−0245 | 02:25:11.63  | −08:24:38.38 | 0.1099   | 5.6/11.3    | 5.7/11.4    | G14   | 1.8            | 20141210       | 2.4         | 146.6 | 2246×2         |
| J0225−0824 | 07:37:44.10  | −46:51:07.96 | 0.0951   | 1.6/2.9     | 1.7/3.0     | G8    | 1.8            | 20141221       | 1.6         | 25.2  | 2500+2100       |
| J0737+4651 | 09:33:47.76  | +21:14:36.41 | 0.1722   | 4.1/11.9    | 4.0/11.7    | G8    | 1.8            | 20150210       | 0.9         | 52.9  | 3000            |
| J0933+2114 | 10:10:43.36  | +06:12:01.42 | 0.0978   | 7.1/12.8    | 7.1/12.8    | G8    | 1.8            | 20150212       | 1.3         | 61.0  | 2410×2         |
| J1010+0612 | 10:17:56.75  | +34:48:50.36 | 0.1440   | 5.4/11.7    | 5.4/11.7    | G8    | 1.8            | 20150207       | 2.8         | 134.9 | 3000            |
| J1017+3448 | 11:05:44.45  | +19:57:46.29 | 0.1043   | 3.8/7.3     | 3.7/7.1     | G8    | 1.8            | 20150208       | 1.6         | 8.6   | 3000            |
| J1105+1957 | 12:00:41.39  | +31:47:46.28 | 0.1161   | 5.7/12.1    | 5.7/12.1    | G8    | 1.8            | 20150212       | 1.6         | 33.2  | 3000            |
| J1200+3147 | 12:01:49.74  | −01:53:27.55 | 0.0907   | 7.0/11.8    | 7.1/12.0    | G8    | 1.8            | 20150211       | 2.0         | 143.2 | 1292×2        |
| J1201−0153 | 15:35:02.26  | +34:55:38.43 | 0.1307   | 5.3/12.3    | 5.4/12.6    | G8    | 1.8            | 20150301       | 1.6         | 93.1  | 3000            |
| J1535+3455 | 16:33:23.58  | +47:18:58.95 | 0.1158   | 3.8/8.0     | 4.0/8.4     | G8    | 1.8            | 20150301       | 1.4         | 175.6 | 3000            |
| J1633+4718 | 21:50:24.70  | −00:52:42.78 | 0.1108   | 5.4/11.0    | 5.5/11.1    | G8    | 1.8            | 20141115       | 1.8         | 53.1  | 3000            |
| J2150−0052 | 22:26:21.65  | +01:43:29.88 | 0.2231   | 2.6/9.3     | 2.5/9.0     | G8    | 1.8            | 20151115       | 1.6         | 79.8  | 3000            |
| J2226+0143 | 22:33:36.41  | +03:32:34.70 | 0.1064   | 3.6/7.0     | 3.7/7.2     | G8    | 1.8            | 20141114       | 1.8         | 6.4   | 3000            |
| J2233+0332 | 22:58:10.01  | −01:15:16.26 | 0.1170   | 3.4/7.1     | 3.4/7.1     | G14   | 1.8            | 20111111       | 2.0         | 10.1  | 2700+3600       |

**First phase (15 sources)**

| Name    | R.A. (J2000) | Decl. (J2000) | Redshift | Sep0 (/kpc) | Sep1 (/kpc) | Grism | Slew width (") | Observing date | Seeing (") | PA (°) | Exposure time (s) |
|---------|--------------|--------------|----------|-------------|-------------|-------|----------------|----------------|-------------|--------|------------------|
| J0101−0957 | 01:01:58.62  | −09:57:50.57 | 0.1523   | 5.3/14.1    | 5.4/14.3    | G3    | 1.8            | 20151105       | 2.0         | 52.2  | 2380×2         |
| J0141−0105 | 01:41:56.81  | −01:05:32.03 | 0.1392   | 6.0/14.7    | 5.9/14.5    | G3    | 1.8            | 20151106       | 3.0         | 5.6   | 2700            |
| J0157+1155 | 01:57:23.82  | +11:55:47.61 | 0.0888   | 4.5/7.5     | 4.5/7.5     | G3    | 2.5            | 20161202       | 1.7         | 154.4 | 3000            |
| J0204−0248 | 01:01:58.62  | −09:57:50.57 | 0.1523   | 5.3/14.1    | 5.4/14.3    | G3    | 1.8            | 20151130       | 2.1         | 75.6  | 2500            |
| J0206−0441 | 02:06:28.41  | −04:41:10.54 | 0.1364   | 5.5/13.2    | 5.4/13.0    | G3    | 2.5            | 20161202       | 1.5         | 82.1  | 3600            |
| J0217−0845 | 02:17:03.46  | −08:45:19.08 | 0.1081   | 6.0/12.0    | 6.2/12.2    | G3    | 2.5            | 20161203       | 2.1         | 59.0  | 3000+3000       |
| J0251−0837 | 02:25:11.63  | −08:24:38.38 | 0.1323   | 4.9/11.4    | 4.8/11.3    | G3    | 2.5            | 20161202       | 1.7         | 7.8   | 3500            |
| J0750+3530 | 07:50:57.26  | +35:30:37.67 | 0.1762   | 3.4/10.3    | 3.4/10.3    | G3    | 2.5            | 20170204       | 2.1         | 141.8 | 3000            |

**Second phase (26 sources)**
### Table 2
(Continued)

| Name         | R.A. (J2000) | Decl. (J2000) | Redshift | Sep0 (″/kpc) | Sep1 (″/kpc) | Grism | Slit width (″) | Observing date UT | Seeing (″) | PA (°) | Exposure time (s) |
|--------------|--------------|---------------|----------|--------------|--------------|-------|---------------|-------------------|------------|--------|------------------|
| J0752+3419   | 07:52:21.86  | +34:19:35.58  | 0.1400   | 3.3/8.1      | 3.1/7.6      | G3    | 1.8           | 20151123         | 1.5        | 59.9   | 3800              |
| J0756+2340   | 07:56:21.00  | +23:40:39.40  | 0.0742   | 6.8/9.6      | 6.8/9.6      | G3    | 1.8           | 20161204         | 3.0        | 48.6   | 3000              |
| J0758+2705   | 07:58:46.99  | +27:05:15.61  | 0.0987   | 3.3/6.0      | 3.4/6.2      | G3    | 1.8           | 20151124         | 1.3        | 73.8   | 3000              |
| J0813+4941   | 08:13:47.49  | +49:41:09.83  | 0.0942   | 3.3/5.8      | 3.4/5.9      | G3    | 2.5           | 20170204         | 2.2        | 139.9  | 3000              |
| J0813+5529   | 08:13:26.77  | +55:29:18.07  | 0.0796   | 5.9/8.8      | 5.9/8.8      | G3    | 2.5           | 20161205         | 2.0        | 178.9  | 2500              |
| J0833+1532   | 08:33:55.49  | +15:32:36.62  | 0.1516   | 4.5/11.9     | 4.5/11.9     | G3    | 2.5           | 20170205         | 2.0        | 149.4  | 3000              |
| J0848+3515   | 08:48:09.69  | +35:15:32.12  | 0.0570   | 5.6/6.2      | 5.7/6.3      | G3    | 2.5           | 20170206         | 2.5        | 66.8   | 3000              |
| J0907+5203   | 09:07:14.44  | +52:03:43.40  | 0.0596   | 7.4/8.5      | 7.4/8.5      | G3    | 2.5           | 20170206         | 2.1        | 11.4   | 2500              |
| J1214+2931   | 12:14:18.25  | +29:31:46.70  | 0.0633   | 6.7/8.2      | 6.7/8.2      | G3    | 1.8           | 20160528         | 1.5        | 61.2   | 3200              |
| J1645+2057   | 16:45:07.91  | +20:57:59.43  | 0.1300   | 4.2/9.8      | 4.2/9.8      | G3    | 1.8           | 20160519         | 2.0        | 155.1  | 3200              |
| J2145+1144   | 21:45:30.39  | +11:44:03.66  | 0.1122   | 3.8/7.8      | 3.7/7.6      | G3    | 1.8           | 20151106         | 2.2        | 93.5   | 2200              |
| J2206+0003   | 22:06:35.08  | +00:03:23.16  | 0.0461   | 4.7/4.3      | 4.5/4.1      | G3    | 1.8           | 20151126         | 1.4        | 156.9  | 2000+2200         |
| J2210+0945   | 22:10:58.06  | +09:45:00.92  | 0.1170   | 4.7/9.9      | 4.5/9.5      | G3    | 1.8           | 20151106         | 1.5        | 19.1   | 2500              |
| J2239+0012   | 22:39:32.21  | +00:12:46.36  | 0.1615   | 4.1/11.4     | 4.2/11.7     | G3    | 1.8           | 20161024         | 1.4        | 178.8  | 3000              |
| J2252+0106   | 22:52:22.35  | +01:06:59.98  | 0.0717   | 3.2/4.4      | 3.1/4.2      | G3    | 2.5           | 20161024         | 1.5        | 126.2  | 2700              |
| J2314+0653   | 23:14:39.21  | +06:53:12.97  | 0.0875   | 4.1/6.7      | 4.2/6.9      | G3    | 1.8           | 20161024         | 1.3        | 157.5  | 2500              |
| J2320+0741   | 23:20:41.53  | +07:41:48.24  | 0.1316   | 4.4/10.2     | 4.5/10.5     | G3    | 2.5           | 20161204         | 1.3        | 106.1  | 3000              |

**Notes.** Sep0: The separation of two cores from the SDSS image. Sep1: The separation of two cores from the 2D spectrum.

\( a \) PA: Position angle of the slit on the sky, in degrees east of north.

\( b \) The exposure times of the observations were originally set to be longer (e.g., 3000 s) but were cut short due to problems of the telescope tracking.
spectra can be extracted with minimum flux loss and contamination. To quantitatively show the robustness of our 1D spectral extraction procedure, we calculate the averaged flux loss and contamination ratios of the six slices for our observed targets. The distributions of flux loss and contamination of the 1D spectra of our dual AGN candidates are shown in Figure 2. In general, the flux loss and contamination amount to only a few per cent. This is corroborated by the high-quality example spectra presented in Figure 3. Part of our targets have multiple observations, and their 1D spectra are stacked via their signal-to-noise ratios.

2.3.3. Subtraction of Contribution of Host Galaxy

The continuum and absorption features of the host galaxy should be subtracted properly from the extracted spectra before deriving the properties of the emission lines. To subtract the continuum and absorption features, the penalized PiXel Fitting software (pPXF; Cappellari & Emsellem 2004; Cappellari 2017) was applied to our long-slit spectra. This code allows one to fully decompose gas emission from stellar absorption features, using a maximum penalized likelihood approach. In pPXF, the MILES library13 (Sánchez-Blázquez et al. 2006) with a wide range of physical parameters was adopted as a template to model the contribution from the host galaxy. Before fitting, all the template spectra were properly convolved to the resolution of our long-slit spectra, and all the prominent emission lines were masked. As an example, the performance of this subtraction is shown in Figure 3 for the J0933+2114 system (as well as in Appendix B for more examples). The consistent results of the flux ratio and FWHM measurements from the LJT long-slit spectra and SDSS fiber spectra as checked in Section 3.3 show that the host subtraction by the pPXF algorithm is generally reasonable for our low-resolution LJT spectra.

2.3.4. Detection of Emission Lines

Typically, nine strong optical emission lines (i.e., Hβ, [O III] λλ 4959, 5007, [O I] λ6300, Hα, [N II] λλ 6549, 6583, and [S II] λλ 6717, 6731) can be detected from the spectra with continuum and absorption features properly subtracted by pPXF, as described in the previous section. Line properties (e.g., flux, FWHM, central wavelength) can be derived by the IDL fitting procedure MPFIT14 (Craig Markwardt 2009). We fit each component of detected emission lines by single or multiple Gaussian(s) to obtain their fluxes, central wavelengths, and FWHMs15. Here we note that an emission line could be detected only with a signal-to-noise ratio (defined as the ratio between the peak of emission line and the standard deviation of the continuum nearby the emission line) greater than 3. For the case shown in Figure 4, we use one Gaussian for the [N II] λ6550 line, one Gaussian for the [N II] λ6585 line, and a pair of Gaussians with the same central wavelength for the broad

---

13 This library contains 985 flux well-calibrated stellar spectra with a wavelength range from 3525 to 7500 Å, with a spectral resolution at FWHM of ~2.51 Å, σ ~64 km s⁻¹.

14 https://pages.physics.wisc.edu/~craigm/idl/fitting.html

15 The FWHM values reported in Table 5 have been corrected for the instrumental broadening effect.
Figure 3. The LJT spectra of dual AGN: J0933+2114 for J0933+2114EN (top) and J0933+2114WS (bottom) showing emission lines Hβ, [O III]λλ 4959,5007, [O I] λλ 6300, Hα, [N II] λλ 6549,6583, and [S II]λλ 6717,6731 at rest-frame wavelengths. We used pPXF to subtract the continuous spectrum and get emission lines. The red lines represent the continuum component of host galaxy, the blue lines represent the narrow emission lines component, and the green lines represent the broad emission lines component.

Figure 4. Spectra fitting for J0933+2114EN (left) and J0933+2114WS (right) near the Hα region. Both galaxies have a broad Hα component. We use one Gaussian for [N II] λ6549, another Gaussian for [N II] λ6583, and a pair of Gaussians for the Hα broad and narrow components that have the same central wavelength, to fit the whole spectral region.

narrow Hα components. If only a narrow component of the Hα emission is detected, then only one Gaussian is used to fit it. A similar fitting strategy is used for other detected emission lines. The error of each parameter is given by the covariance matrix provided by MPFIT. The fitting results of all well-detected emission lines are presented in Tables 3 and A1.

3. Results

3.1. Identification and Classification of AGNs

In this Section, we attempt to identify AGNs and classify them from the observed targets based on the analysis of the measured emission lines in the optical range. The details are given in the following. We also indicate the caveats of the current AGN identifications purely based on optical data at the end of this section.

Here, we adopt the criteria developed by Hao et al. (2005) to identify Type I AGNs: (1) FWHM of Hα > 1200 km s$^{-1}$ and h(Hα broad)/h(Hα narrow) > 0.1; or (2) FWHM of Hα > 2200 km s$^{-1}$, where h(Hα broad) and h(Hα narrow) are the heights of the Hα broad- and narrow-line components, respectively. The height is given by the peak of the Gaussian fits.

For Type II AGNs (i.e., those with narrow emission lines), we adopt the so-called BPT diagrams (see Baldwin et al. 1981; Veilleux & Osterbrock 1987; Kewley et al. 2001, hereafter Ke01; Kauffmann et al. 2003, hereafter Ka03; Kewley et al. 2006, hereafter Ke06) to identify them, based on the four optical emission line flux ratios, i.e., [O III]λλ 5007/Hβ, [N II] λ6583/Hα, [S II] λλ 6717,6731/Hα, and [O I] λλ 6300/Hα. The fluxes used have not been corrected for any reddening and extinction effects. As the lines involved in those ratios have close central wavelengths, the nonconsideration of reddening corrections has minor impact on the results (e.g., Kauffmann et al. 2003). The so-called “maximum starburst line” on the BPT diagram is derived from the upper limit of the theoretical pure stellar photoionization models (Ke01, Ka03, Ke06). As Figure 5 shows, sources above the red solid line (Ke01) are likely to be dominated by AGNs, below the blue dashed line (Ka03) are purely star-forming galaxies, between the red solid line (Ke01) and the blue dashed line (Ka03) are AGNs/star-forming composite galaxies (Comp). In the AGN region, Seyferts and low-ionization nuclear emission line region (LINERs) populate dominantly above and below the blue solid line (Ke06), respectively. More details of the BPT diagrams are described in Kewley et al. (2006). Based on those BPT diagrams, the galaxies are classified into star-forming galaxies (H I), AGN/star-forming composite galaxies (Comp), Seyfert galaxies (Seyfert), LINERs, and ambiguous galaxies (ambiguous AGN). Ambiguous galaxies are those that classified as one subtype of AGN in one or two of the diagram(s) but classified as another subtype of AGN in the remaining diagram(s). The detail classifications of our dual AGNs are presented in Table 4.
Fluxes of Well-detected Emission Lines

| Name          | $f_{\text{H}\beta}$ | $f_{\text{O III} \lambda 4959}$ | $f_{\text{O III} \lambda 5007}$ | $f_{\text{O II} \lambda 3727}$ | $f_{\text{N II} \lambda 6583}$ | $f_{\text{N II} \lambda 6549}$ | $f_{\text{S II} \lambda 6717}$ | $f_{\text{S II} \lambda 6731}$ |
|---------------|----------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| J0151-0245WN  | 75 ± 23              | 31 ± 11                         | 128 ± 12                        | 115 ± 12                        | 85 ± 14                         | 68 ± 12                         | 231 ± 18                        | 145 ± 17                        | 120 ± 17                        |
| J0151-0245ES  | 76 ± 22              | 52 ± 15                         | 153 ± 13                        | 109 ± 15                        | 213 ± 18                        | 247 ± 18                        | 445 ± 11                        | 272 ± 14                        | 164 ± 14                        |
| J0933+2114EN  | 131 ± 84             | 437 ± 59                        | 1494 ± 59                       | 106 ± 37                        | 540 ± 137                       | 1663 ± 140                      | 1238 ± 124                      | 414 ± 122                      | 193 ± 93                        |
| J0933+2114WS  | 399 ± 33             | 382 ± 31                        | 1192 ± 30                       | 215 ± 44                        | 254 ± 54                        | 929 ± 68                        | 609 ± 57                        | 229 ± 52                        | 137 ± 48                        |
| J1017+3448NW  | 313 ± 106            | 286 ± 100                       | 976 ± 104                       | 128 ± 52                        | 365 ± 81                        | 1115 ± 71                       | 665 ± 59                        | 283 ± 18                        | 152 ± 15                        |
| J1017+3448SE  | 118 ± 52             | 309 ± 40                        | 1191 ± 40                       | 77 ± 38                         | 226 ± 120                       | 723 ± 142                       | 570 ± 96                        | 98 ± 44                         | 89 ± 45                         |
| J1105+1957EN  | 197 ± 14             | 58 ± 15                         | 195 ± 17                        | 57 ± 8                          | 376 ± 14                        | 1221 ± 13                       | 893 ± 11                        | 268 ± 17                        | 242 ± 15                        |
| J1105+1957WS  | 110 ± 11             | 51 ± 19                         | 230 ± 21                        | 33 ± 6                          | 51 ± 8                          | 247 ± 13                        | 176 ± 13                        | 83 ± 10                         | 58 ± 8                          |
| J1633+4718N   | 205 ± 23             | 93 ± 19                         | 320 ± 20                        | 96 ± 32                         | 104 ± 32                        | 1023 ± 36                       | 471 ± 36                        | 182 ± 12                        | 142 ± 15                        |
| J1633+4718S   | 203 ± 42             | 135 ± 16                        | 545 ± 29                        | 167 ± 36                        | 1177 ± 67                       | 1163 ± 176                      | 576 ± 76                        | 128 ± 17                        | 114 ± 17                        |
| J2258-0115EN  | 84 ± 12              | 22 ± 10                         | 96 ± 12                         | 18 ± 9                          | 24 ± 5                          | 273 ± 16                        | 137 ± 15                        | 63 ± 12                         | 43 ± 8                          |
| J2258-0115WS  | 76 ± 39              | 127 ± 13                        | 425 ± 23                        | 61 ± 8                          | 64 ± 10                         | 128 ± 16                        | 109 ± 11                        | 21 ± 4                          | 20 ± 5                          |

Note. Fluxes are in units of $10^{-17}$ erg cm$^{-2}$ s$^{-1}$. The fluxes of the H$\beta$ and H$\alpha$ emission lines are both for the narrow-line component.
The BPT diagrams have been widely used to identify optical AGNs. However, some caveats remain when using the BPT diagrams. We note that the LINERs, Comps, and ambiguous galaxies identified by the BPT technique may suffer contamination from the H II or star-forming galaxies, given the current line ratio measurement errors and the potential systematics of the theoretical criteria (e.g., Kauffmann & Heckman 2009; Stern & Laor 2013; Azadi et al. 2017). Some studies also indicate that the distinct regions of AGNs and H II on the BPT diagrams have some overlaps (e.g., Kauffmann & Heckman 2009; Heckman & Best 2014). This empirical identification will miss the lineless AGNs, due to their extremely weak, sometimes completely undetected emission lines (Cid Fernandes et al. 2010; Netzer 2015). Not all of the AGN populations can be recovered by only using a single wave band observation (e.g., Azadi et al. 2017). The further follow-up observations by either radio or X-rays could provide more vital constraints on the nature of the identified dual AGNs. It is worth mentioning that identifying outflows in these optical emission line profiles could further provide indirect evidence on the nature of our dual AGN candidates, since the outflows around NLRs can be driven by AGN feedback (e.g., Di Matteo et al. 2005; Hopkins et al. 2005; Crenshaw et al. 2015; Müller-Sánchez et al. 2016; Nevin et al. 2018). However,
as shown in Nevin et al. (2018), the velocity offset of the outflows is typically within 1000 km s$^{-1}$, and the current spectroscopy observations ($R \sim 300$) cannot be used to identify such outflow features. Our ongoing long-slit spectroscopy observations by the Double Spectrograph (DBSP) with resolving power of around 2000 mounted on the Hale 5.1 m telescope will allow us to do such analysis and provide more constraints on the nature of dual AGN candidates.

### 3.2. Dual AGN Sample

Based on long-slit observations of 41 candidates with the YFOSC and the identification criteria presented in Section 3.1, we have found 16 likely dual AGNs. For the remaining 25 targets, 12 of them are AGN and normal galaxy pairs, 5 of them are AGN and star-forming galaxy pairs, 1 target is an AGN and star nonphysical pair, and the other 7 targets are hard to identify either due to unresolved 2D long-slit spectra or low quality spectra. In our dual AGN sample, 15 are newly found, and only one (J1214+2931) has been revealed with X-ray imaging by Secrest et al. (2017). The detailed properties of the 16 likely dual AGNs are presented in Table 5. The high efficiency of our systematic searching method is about 39\% (16/41). Among our identified dual AGNs, 28.1\% (9/32) are Type I AGNs, 25.0\% (8/32) Seyfert 2\%, 21.9\% (7/32) LINERs, 18.8\% (6/32) Comp, and 6.3\% (2/32) ambiguous classification.

As an example, we briefly discuss the properties of dual AGN J0933+2114. As shown in Figure 1, the two spectra of the dual cores, i.e., J0933+2114EN and J0933+2114WS, are spatially well resolved, allowing robust identification and classification of the system.

J0933+2114EN has a redshift of 0.17234 $\pm$ 0.00005, and the FWHM of the NLR is 629 $\pm$ 46 km s$^{-1}$, as measured from the [O III] 5007 line. The spectrum of J0933+2114EN has a broad-line component, as shown in Figure 4. The FWHM of the BLR is 5091 $\pm$ 53 km s$^{-1}$, as given by the H$\alpha$ broad-line component. This value of BLR is much greater than 2200 km s$^{-1}$, thus J0933+2114EN is clearly a Type I AGN.

J0933+2114WS has a redshift of 0.17321 $\pm$ 0.00005 and the FWHM of the NLR is 548 $\pm$ 53 km s$^{-1}$, again measured from the [O III] 5007 line. J0933+2114WS also has a broad-line component, as shown in Figure 4. The FWHM of the BLR is 4956 $\pm$ 155 km s$^{-1}$, as measured from the H$\alpha$ broad-line component. The velocity of the BLR is again greater than 2200 km s$^{-1}$, confirming it a Type I AGN.

J0933+2114 is thus identified as a dual AGN composed of two Type I AGNs. The two optical cores have a separation of 12.3 kpc and a velocity offset of 261 $\pm$ 21 km s$^{-1}$. The distribution of dual AGNs identified in the current work in the plane of redshift versus projection distance is presented in Figure 6, together with those previously known in the literature (Paper I). Dual AGNs detected with hard X-ray or radio observations have redshifts systematically smaller than those found by the double-peak technique. Dual AGNs identified in the current work have redshifts ranging from 0.0461 to 0.1722 and separations ranging from 4.3 to 14.2 kpc. As Figure 6 shows, our dual AGN found in this work make the dual AGN sample more complete in the redshift space. For our sample, the velocity offsets of the two cores range from 57 to 300 km s$^{-1}$ (Figure 7), in good agreement with previous results (50–300 km s$^{-1}$; Comerford et al. 2013; Koss et al. 2016).

A detailed analysis of the remaining 15 likely dual AGNs in the current work is presented in Appendix B. In total, we have found 16 likely dual AGNs and significantly increased the number of known dual AGNs.

#### 3.3. Validation of Measurements

Given the relatively low resolution of our spectra (especially those of G3), the accuracies of the flux ratio, redshift, separation, and FWHM measurements presented here should be examined. Doing so, we compare our results with those derived from the SDSS fiber spectra that have a higher spectral resolution ($R \sim 2200$).

##### 3.3.1. Flux Ratios

To check the reliability of our BPT diagram results, the flux ratios of our likely dual AGNs are compared to those derived from the SDSS spectra for part of the optical cores. First, we compare the flux ratios measured from our long-slit spectra with those from the SDSS fiber spectra. For most of the two cores in dual AGNs, only one core has been identified as an AGN in the SDSS, and the other core has no SDSS spectrum. There are 32 optical cores in the 16 dual AGNs, but only 20 cores have SDSS spectra (Table 4). As Figure 8 shows, flux ratio measurements from our spectra are generally consistent with those from the SDSS. Here we note that the flux measurements of emission lines from SDSS spectra are similar to those of our long-slit spectra, as described in Sections 2.3.3 and 2.3.4. As shown in Table 4, BPT classifications based on the flux ratio measurements from our long-slit spectra are totally in agreement with those based on the SDSS spectra, implying the reliability of the former measurements.

##### 3.3.2. Redshifts

To check the wavelength calibration accuracy of our long-slit spectra, the derived redshifts of those likely dual AGNs are compared to those deduced from the SDSS spectra. The distribution of redshifts of the targeted candidates and our dual AGNs is displayed in Figure 9. As shown in Figure 10, the results agree with each other very well. The median value and standard deviation of the redshift differences are only 10 and 23 km s$^{-1}$, respectively, confirming the good wavelength calibration of our long-slit spectra.

##### 3.3.3. Separations

To check whether the 2D spectra are actually from the two optical cores of our selected merging galaxies, the separations between the two cores from the SDSS images are compared to those from the 2D spectra for the 16 identified dual AGNs. Figure 11 clearly shows that the separations fitted from the 2D spectra are in excellent agreement with those from the SDSS images. The median value and standard deviation of the separation differences are just 0 and 0.2 kpc, respectively, confirming that our observed 2D spectra are actually from the two cores of merging galaxies.

##### 3.3.4. FWHMs

FWHM is an important parameter that characterizes the NLR and BLR of an AGN. The velocity width of the BLR is large enough to be resolved by our spectra and is thus well measured. For the NLRs, the instrumental broadening of our spectra is comparable or slightly higher than their velocity widths. By comparing with the FWHMs deduced from the SDSS spectra,
| Name                  | AGN            | $Z_{em}$ | $FWHM_{AGN}(\text{km s}^{-1})$ | $FWHM_{Gal}(\text{km s}^{-1})$ | $V_{\text{offset}}(\text{km s}^{-1})$ | Sep ($\arcsec$,kpc) | $W_1$, $W_2$ mag | Radio | Classification |
|----------------------|----------------|----------|---------------------------------|---------------------------------|----------------------------------------|---------------------|-----------------|-------|----------------|
| First phase (6 Dual AGNs) |
| J015107.39-024526.87 | J0151−0245WN   | 0.04774 ± 0.00008 | 262 ± 63                       | ---                             | 57 ± 28                               | 5.1/4.8             | 0.030           | N     | LINER          |
|                      | J0151−0245ES   | 0.04793 ± 0.00005 | 471 ± 36                       | ---                             | ---                                   | ---                 | ---             | Y     | LINER          |
| J093347.76+211436.41 | J0933+2114EN   | 0.17234 ± 0.00005 | 629 ± 46                       | 5091 ± 153                     | 261 ± 21                              | 4.2/12.3            | 0.714           | Y     | Type I AGN     |
|                      | J0933+2114WS   | 0.17321 ± 0.00005 | 548 ± 53                       | 4956 ± 155                     | 243 ± 21                              | 5.6/14.2            | 0.873           | N     | Type I AGN     |
| J110757.07+344846.61 | J1107+3448WN   | 0.14321 ± 0.00005 | 778 ± 41                       | ---                             | 243 ± 21                              | 5.6/14.2            | 0.993           | Y     | Type I AGN     |
|                      | J1107+3448ES   | 0.14400 ± 0.00005 | 614 ± 48                       | 3255 ± 243                     | ---                                   | ---                 | 0.872           | N     | Type I AGN     |
| J110544.48+195750.06 | J1105+1957EN   | 0.10421 ± 0.00005 | 487 ± 46                       | ---                             | 84 ± 21                               | 3.9/7.4             | 0.329           | Y     | Seyfert        |
|                      | J1105+1957WS   | 0.10440 ± 0.00005 | 399 ± 50                       | ---                             | ---                                   | ---                 | ---             | N     | Type I AGN     |
| Second phase (10 Dual AGNs) |
| J225810.01-011516.26 | J2258−0115EN   | 0.11609 ± 0.00005 | 738 ± 43                       | ---                             | 300 ± 21                              | 3.2/6.9             | 0.652           | Y     | Type I AGN     |
|                      | J2258−0115WS   | 0.11709 ± 0.00005 | 650 ± 46                       | 2929 ± 347                     | ---                                   | ---                 | ---             | N     | Type I AGN     |

Note. $Z_{em}$: Median redshift of main emission lines detected with good signal-to-noise ratios. $FWHM_{AGN}$: $FWHM$ of narrow-line region represented by the $FWHM$ of the [O III] $\lambda$5007 line. $FWHM_{Gal}$: $FWHM$ of broad-line region represented by the $FWHM$ of the Hα broad component. $V_{\text{offset}}$: velocity offset of the two AGN cores. Sep: separation of the two AGN optical cores in arcsec and in kpc. $W_1$, $W_2$: magnitude difference in the Wide-field Infrared Survey Explorer (WISE) $W_1$ and $W_2$ bands for the two resolved/unresolved cores. Radio: N(NO), Y(YES), whether detected as the radio-excess AGN result from radio power versus Hα luminosity. SyII: Seyfert 2. Classification: classifications of the two AGN optical cores.
we examine the accuracy of the FWHMs of NLRs measured from our spectra. The results plotted in Figure 12 show reasonable agreement. The median value and standard deviation of the differences are only 7 and 120 km s\(^{-1}\), respectively.

### 4. Discussion

#### 4.1. Implications for Dual AGN Systematic Searching

A systematic search for dual AGNs generally includes three steps. To start with, a large sample of potential candidates of dual AGNs is required. Then, follow-up spectroscopy is carried out to exclude most contamination. As a final step, radio or hard X-ray observations provide vital evidence of activity. In this process, the first step is the key to obtaining a large sample of candidate dual AGNs. As mentioned in Section 1, several previous attempts proposed to systematically search for dual AGNs, including that based on DPAGNs (e.g., Liu et al. 2010, 2011; Shen et al. 2011; Comerford et al. 2012) and the infrared colors of AGNs (e.g., Satyapal et al. 2014, 2017). Hundreds of DPAGNs have been selected from the DEEP2 Galaxy Redshift Survey (e.g., Gerke et al. 2007) and from the SDSS survey (e.g., Wang et al. 2009; Liu et al. 2010; Smith et al. 2010). However, follow-up spectroscopic observations reveal that only 2\%–5\% of the selected DPAGNs are bona fide dual AGNs (e.g., Liu et al. 2011; Shen et al. 2011; Comerford et al. 2012). The main reason underlying this low efficiency is the large contamination of rotating disks or biconical outflows of the NLR gas surrounding a single AGN that also produce double-peaked emission line profiles (e.g., Smith et al. 2012; Comerford & Greene 2014).

Satyapal et al. (2017) proposed an alternative new method to search for dual AGN candidates based on the mid-infrared color \(W_1 - W_2\) from the WISE survey (e.g., Wright et al. 2010). They argue that this method could discover the buried population of dual AGNs missed by optical observations. This method is highly powerful for luminous and highly obscured AGN systems, especially those systems including Type I AGNs (e.g., Hickox et al. 2017; Satyapal et al. 2017). However, this method may not be efficient at identifying dual AGNs composed of only Type II AGNs. In Figure 13, we show the \(W_1 - W_2\) color distribution of our dual AGN sample. The Type I AGN or dual AGN systems that contain at least one Type I AGN show redder \(W_1 - W_2\) colors (>0.6 mag).
Comparison of flux ratios as measured from our long-slit and SDSS fiber spectra for (a) \(\log ([\text{O} \text{ III}]/H\alpha)_{\text{LT}}\) vs. \(\log ([\text{O} \text{ III}]/H\alpha)_{\text{SDSS}}\), (b) \(\log ([\text{N} \text{ II}]/H\alpha)_{\text{LT}}\) vs. \(\log ([\text{N} \text{ II}]/H\alpha)_{\text{SDSS}}\), (c) \(\log ([\text{S} \text{ II}]/H\alpha)_{\text{LT}}\) vs. \(\log ([\text{S} \text{ II}]/H\alpha)_{\text{SDSS}}\), and (d) \(\log ([\text{O} I]/H\alpha)_{\text{LT}}\) vs. \(\log ([\text{O} I]/H\alpha)_{\text{SDSS}}\).

Comparison of redshifts yielded by our long-slit and SDSS spectra for part of the cores in our dual AGN sample.

Figure 8. Comparison of flux ratios as measured from our long-slit and SDSS fiber spectra.

Figure 9. Redshift distribution for our targeted (red) and dual AGNs (blue).

Figure 10. Comparison of redshifts yielded by our long-slit and SDSS spectra.
FIRST catalog. The radio powers are then calculated for all the dual AGN candidates again assuming a power-law index of $-0.7$. To explore those radio radiation natures, the diagram between $P_{1.4 \text{ GHz}}$ and $L_{\text{Hi}}$ is shown in Figure 16. The plot clearly show that all the systems have radio powers over 10 times larger than those expected from the H$_\alpha$-traced star formation rates, implying significant radio excesses from AGN activities. The results partly show that the candidates found in the current work are promising dual AGN systems.

To conclude, compared to previous methods, the systematic method of searching for dual AGNs employed in the current work is relatively efficient, cost-effective, and capable of building a large sample of dual AGNs.

### 4.2. Potential Applications of the Sample

As mentioned earlier, this newly identified dual AGN sample, together with those known dual AGN in the literature, could provide vital information for understanding the coevolution of SMBHs and their host galaxies. For example, by measuring the black hole masses and the velocity dispersions of the individual AGNs in those dual AGN systems, one can derive the $M_{\text{BH}}$–$\sigma$ relation for the dual AGN systems and test whether the relation is consistent with that found for normal galaxies and single AGNs (e.g., Komossa & Xu 2007; Fu et al. 2011a). In addition, one can explore the kinematics of gas and stellar components in those systems and investigate whether their behaviors are the same or not (e.g., Villforth & Hamann 2015; Zhang et al. 2016).
In the forthcoming papers of this series, we will present results demonstrating the power of our dual AGN sample to understand the above issues.

5. Conclusion

Using an innovative method of systematically searching for and identifying dual-AGN systems among kpc-scale merging galaxies, a total of 222 candidates are selected. As the first results of our ASTRO-DARING project, we have obtained long-slit spectroscopic observations for 41 targets between 2014 November and 2017 February using the YFOSC mounted on the LJT of YNAOs.

By careful data reduction, 1D spectra extraction, emission line profile fitting, and AGN classification (based on the Balmer emission line widths and emission line ratios), 16 likely dual AGNs are finally identified (15 of them are found for the first time).

Our new searching approach is efficient (about 40%, 16/41) and cost-effective. With this new method, we plan to construct the current largest sample of dual AGNs (>50) and better understand the coevolution of host galaxies and their SMBHs.

We acknowledge the support of the staff of the Lijiang 2.4 m telescope. Fund for the telescope has been provided by the Chinese Academy of Sciences and the People’s Government of Yunnan Province. The work of J.-M. B. is supported by the National Natural Science Foundation of China grants 11833006, 11811530289, and 11903027. It is a pleasure to thank Dr. Sarah Bird for thoroughly reading the manuscript and improving the language significantly. We thank Hai-Cheng Feng, Kai-Xing Lu, and Ding-Rong Xiong for their assistance.

This work has made use of data products from the LJT (Lijiang 2.4 m telescope), SDSS, FIRST, and WISE.

Appendix A

FWHM of Well-detected Emission Lines
Two sets of AGN spectra are spatially resolved, as shown in Figure B1, so the two cores, i.e., J0151−0245WN and J0151−0245ES, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B2. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two cores, no broad-line components are detected; we therefore use the BPT diagram to classify their types (Figure B3). According to the diagnosis, both cores are classified as LINERs.

Object J015107.39-024526.87 has been revealed as a dual AGN composed of two LINERs. This dual AGN has a separation of 4.8 kpc and a velocity offset of 57 ± 28 km s\(^{-1}\).

Two sets of AGN spectra are spatially resolved, as shown in Figure B4, so the two cores, i.e., J0117+3448WN and J0117+3448ES, can be identified separately.
The fitting of the extracted 1D spectra of the two cores is shown in Figure B5. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J1017+3448WN does not show broad lines (Figure B5). We use the BPT diagram to distinguish this AGN shown in Figure B6. It is classified as a Seyfert (AGN). The spectrum of J1017+3448ES has broad lines (Figure B5; FWHM > 2000 km s\(^{-1}\) as measured from the H\(\alpha\) broad-line component), and thus it is a Type I AGN.

Object J101757.07+344846.61 has been revealed as a dual AGN composed of a Seyfert (J1017+3448WN) and a Type I AGN (J1017+3448ES). This dual AGN has a separation of 14.2 kpc and a velocity offset of 243 ± 21 km s\(^{-1}\).

**Dual AGN: J110544.48+195750.06**

Two sets of AGN spectra are spatially resolved, as shown in Figure B7, so the two cores, i.e., J1105+1957EN and J1105+1957WS, can be identified separately.

The fitting of the extracted 1D spectra of the two cores is shown in Figure B8. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two
cores, no broad-line components are detected; we therefore use the BPT diagram to classify their types (Figure B9). According to the diagnosis, J1105+1957EN is classified as a Comp (AGN), and J1105+1957WS is classified as a Seyfert (AGN).

Object J110544.48+195750.06 has been revealed as a dual AGN composed of an ambiguous galaxy (AGN; J1105+1957EN) and a Seyfert (J1105+1957WS). This dual AGN has a separation of 7.4 kpc and a velocity offset of 84 ± 21 km s⁻¹.

Dual AGN J163323.58+471858.95

Two sets of AGN spectra are spatially resolved, as shown in Figure B10, so the two cores, i.e., J1633+4718N and J1633+4718S, can be identified separately.

The fitting of the extracted 1D spectra of the two cores is shown in Figure B11. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J1633+4718N does not show broad lines (Figure B11).
use the BPT diagram to distinguish this AGN shown in Figure B12. The J1633+4718N is revealed as an ambiguous galaxy (AGN). The spectrum of J1633+4718S has broad lines (Figure B11). The FWHM of the BLR is 1965 ± 66 km s$^{-1}$ measured from the H$\alpha$ broad-line component, and h(Hbroad)/h(Hnarrow) is 0.29 (>0.1). According to Hao et al. (2005), J1633+4718S is a Type I AGN.

Object J163323.58+471858.95 has been revealed as a dual AGN composed of an ambiguous galaxy (AGN, J1633+4718N) and a Type I AGN (J1633+4718S). This dual AGN has a separation of 8.0 kpc and a velocity offset of 153 ± 21 km s$^{-1}$.

**Figure B7.** Same as Figure 1 but for J1105+1957.

**Figure B8.** Same as Figure 3 but for J1105+1957. The spectra are from LJT.

**Figure B9.** Same as Figure 5 but for J1105+1957.

Dual AGN J225810.01-011516.26

Two sets of AGN spectra are spatially resolved, as shown in Figure B13, so the two cores, i.e., J2258−0115EN and J2258−0115WS, can be identified separately.

The fitting of the extracted 1D spectra of the two cores is shown in Figure B14. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J2258−0115EN does not show broad lines (Figure B14). We use the BPT diagram to distinguish this
AGN shown in Figure B15, and it is classified as a Comp (AGN). The spectrum of J2258−0115WS has broad lines (Figure B14; FWHM > 2000 km s\(^{-1}\) as measured from the H\(\alpha\) broad-line component), and thus it is a Type I AGN.

Object J225810.01−011516.26 has been revealed as a dual AGN composed of an ambiguous galaxy (AGN: J2258−0115EN) and a Type I AGN (J2258−0115WS). This dual AGN has a separation of 6.9 kpc and a velocity offset of 300 ± 21 km s\(^{-1}\).
Dual AGN J021703.81-084515.97

Two sets of AGN spectra are spatially resolved, as shown in Figure B16, so the two cores, i.e., J0217-0845EN and J0217-0845WS, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B17. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two cores, no broad-line components are detected; we therefore use the BPT diagram to classify their types (Figure B18). According to the diagnosis, both cores are classified as LINERs.

Object J021703.81-084515.97 has been revealed as a dual AGN composed of two LINERs (J0217-0845EN and J0217-0845WS). This dual AGN has a separation of 12.0 kpc and a velocity offset of 90 ± 40 km s⁻¹.

Dual AGN J075621.37+234043.97

Two sets of AGN spectra are spatially resolved, as shown in Figure B19, so the two cores, i.e., J0756+2340EN and J0756+2340WS, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B20. The redshifts, FWHMs of emission lines,
and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two cores, no broad-line components are detected; we therefore use BPT diagram to classify their types (Figure B21). According to the diagnosis, J0756+2340EN is classified as a Comp (AGN), and J0756+2340WS is classified as a LINER (AGN).

Object J075621.37+234043.97 has been revealed as a dual AGN composed of an ambiguous AGN (J0756+2340EN) and
a LINER (J0756+2340WS). This dual AGN has a separation of 9.6 kpc and a velocity offset of 120 ± 40 km s$^{-1}$.

**Dual AGN J081347.49+494109.83**

Two sets of AGN spectra are spatially resolved, as shown in Figure B22, so the two cores, i.e., J0813+4941WN and J0813+4941ES, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B23. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J0813+4941WN has broad lines (Figure B23; FWHM > 2000 km s$^{-1}$ as measured from the Hα broad-line component), and thus it is a Type I AGN. The spectrum of J0813+4941ES only has a narrow-line component. We use the BPT diagram to distinguish this AGN shown in Figure B24, and it is classified as a Comp (AGN).

Object J081347.49+494109.83 has been revealed as a dual AGN composed of a Type I AGN (J0813+4941WN) and a Comp (J0813+4941ES). This dual AGN has a separation of 5.8 kpc and a velocity offset of 150 ± 40 km s$^{-1}$.
Dual AGN J083355.49+153236.62

Two sets of AGN spectra are spatially resolved, as shown in Figure B25, so the two cores, i.e., J0833+1532WN and J0833+1532ES, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B26. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J0833+1532WN only has a narrow-line component. We use the BPT diagram to distinguish this AGN shown in Figure B27, and it is classified as a Seyfert (AGN). The spectrum of J0833+1532ES has broad lines (Figure B26; FWHM > 2000 km s$^{-1}$ as measured from the H$_\alpha$ broad-line component), and thus it is a Type I AGN.

Object J083355.49+153236.62 has been revealed as a dual AGN composed of a Seyfert (J0833+1532WN) and a Type I AGN (J0833+1532ES). This dual AGN has a separation of 11.9 kpc and a velocity offset of 60 ± 40 km s$^{-1}$.

Dual AGN J084809.69+351532.12

Two sets of AGN spectra are spatially resolved, as shown in Figure B28, so the two cores, i.e., J0848+3515EN and J0848+3515WS, can be identified separately.
The fitting of the extracted 1D spectra of the two cores are shown in Figure B29. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J0848+3515EN only has a narrow-line component. We use the BPT diagram to distinguish this AGN shown in Figure B30, and it is classified as a Seyfert (AGN). The spectrum of J0848+3515WS has broad lines (Figure B29; FWHM > 2000 km s$^{-1}$ as measured from the H$\alpha$ broad-line component), and thus it is a Type I AGN.

Object J084809.69+35132.12 has been revealed as a dual AGN composed of a Seyfert (J0848+3515EN) and a Type I AGN (J0848+3515WS). This dual AGN has a separation of 6.2 kpc and a velocity offset of $60 \pm 40$ km s$^{-1}$.
Two sets of AGN spectra are spatially resolved, as shown in Figure B31, so the two cores, i.e., J0907+5203EN and J0907+5203WS, can be identified separately. The fitting of the extracted 1D spectra of the two cores are shown in Figure B32. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two cores, no broad-line components are detected; we therefore use the BPT diagram to classify their types (Figure B33). According to the diagnosis, J0907+5203EN is classified as ambiguous AGN, and J0907+5203WS is classified as a Seyfert (AGN).

Object J090714.61+520350.61 has been revealed as a dual AGN composed of an ambiguous galaxy (J0907+5203EN) and a Seyfert (J0907+5203WS). This dual AGN has a separation of 8.5 kpc and a velocity offset of $150 \pm 40$ km s$^{-1}$.

Two sets of AGN spectra are spatially resolved, as shown in Figure B34, so the two cores, i.e., J1214+2931EN and J1214+2931WS, can be identified separately.
The fitting of the extracted 1D spectra of the two cores are shown in Figure B35. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. The spectrum of J1214+2931EN only has a narrow-line component. We use the BPT diagram to distinguish this AGN shown in Figure B36, and it is classified as a Seyfert (AGN). The spectrum of J1214+2931WS has broad lines (Figure B35; FWHM > 2000 km s$^{-1}$ as measured from the H$\alpha$ broad-line component), and thus it is a Type I AGN.

Object J121418.25+293146.70 has been revealed as a dual AGN composed of a Seyfert (J1214+2931EN) and a Type I AGN (J1214+2931WS). This dual AGN has a separation of 9.3 kpc and a velocity offset of 60 ± 40 km s$^{-1}$.

**Dual AGN J164507.91+205759.43**

Two sets of AGN spectra are spatially resolved, as shown in Figure B37, so the two cores, i.e., J1645+2057WN and J1645+2057ES, can be identified respectively.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B38. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two
cores, no broad-line components are detected; we therefore use the BPT diagram to classify their types (Figure B39). According to the diagnosis, J1645+2057WN is classified as a Seyfert, and J1645+2057ES is classified as a Comp (AGN).

Object J164507.91+205759.43 has been revealed as a dual AGN composed of a Seyfert (J1645+2057WN) and a Comp (J1645+2057ES). This dual AGN has a separation of 9.8 kpc and a velocity offset of $270 \pm 40$ km s$^{-1}$.

**Dual AGN J220634.97+000327.57**

Two sets of AGN spectra are spatially resolved, as shown in Figure B40, so the two cores, i.e., J2206+0003WN and J2206+0003ES, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B41. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from
the 1D spectra, are presented in Tables 4 and 5. For the two cores, no broad-line components are detected; we therefore use BPT diagram to classify their types (Figure B42). According to the diagnosis, both cores are classified as LINERs (AGN).

Object J220634.97+000327.57 has been revealed as a dual AGN composed of two LINERs (J2206+0003WN and J2206+0003ES). This dual AGN has a separation of 4.3 kpc and a velocity offset of 120 ± 40 km s⁻¹.

Dual AGN J231439.21+065312.97

Two sets of AGN spectra are spatially resolved, as shown in Figure B43, so the two cores, i.e., J2314+0653WN and J2314+0653ES, can be identified separately.

The fitting of the extracted 1D spectra of the two cores are shown in Figure B44. The redshifts, FWHMs of emission lines, and emission line flux ratios of the two cores, measured from the 1D spectra, are presented in Tables 4 and 5. For the two cores,
no broad-line components are detected; we therefore use the BPT diagram to classify their types (Figure B45). According to the diagnosis, J2314+0653WN is classified as a Seyfert (AGN) and J2314+0653ES is classified as a Comp (AGN).

Object J231439.21+065312.97 has been revealed as a dual AGN composed of a Seyfert (J2314+0653WN) and a LINER (J2314+0653ES). This dual AGN has a separation of 6.7 kpc and a velocity offset of $90 \pm 40$ km s$^{-1}$. 

Figure B40. Same as Figure 1 but for J2206+0003.

Figure B41. Same as Figure 3 but for J2206+0003. The spectra are from LJT.

Figure B42. Same as Figure 5 but for J2206+0003.
Figure B43. Same as Figure 1 but for J2314+0653.

Figure B44. Same as Figure 3 but for J2314+0653. The spectra are from LJT.

Figure B45. Same as Figure 5 but for J2314+0653.
