The Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) Quasar Survey: The Fourth and Fifth Data Releases

Su Yao\textsuperscript{1,2,6}, Xue-Bing Wu\textsuperscript{1,3}, Y. L. Ai\textsuperscript{4}, Jinyi Yang\textsuperscript{1,3}, Qian Yang\textsuperscript{1,3}, Xiaoyi Dong\textsuperscript{3}, Ravi Joshi\textsuperscript{1}, Su Yao\textsuperscript{1,2,6}, Xiaotong Feng\textsuperscript{1,3}, Yuming Fu\textsuperscript{1,3}, Wen Hou\textsuperscript{4}, A.-L. Luo\textsuperscript{2}, Xiao Kong\textsuperscript{2}, Yuanqi Liu\textsuperscript{3}, Y.-H. Zhao\textsuperscript{2}, Y.-X. Zhang\textsuperscript{2}, H.-L. Yuan\textsuperscript{2}, and Shiying Shen\textsuperscript{3}

\textsuperscript{1}Kavli Institute for Astronomy and Astrophysics, Peking University, Beijing 100871, People's Republic of China; yaosu@pku.edu.cn
\textsuperscript{2}National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, People’s Republic of China
\textsuperscript{3}Department of Astronomy, School of Physics, Peking University, Beijing 100871, People’s Republic of China
\textsuperscript{4}School of Physics and Astronomy, Sun Yat-Sen University, Guangzhou 510275, People’s Republic of China
\textsuperscript{5}Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, People’s Republic of China

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Abstract

We present Data Releases 4 and 5 of the quasar catalog from the quasar survey by the Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST), which includes quasars observed between 2015 September and 2017 June. There are a total of 19,253 quasars identified by visual inspections of the spectra. Among them, 11,458 were independently discovered by LAMOST, in which 3296 were reported by the SDSS DR12 and DR14 quasar catalog after our survey began, while the remaining 8162 are new discoveries of LAMOST. We provide the emission line measurements for H\textsc{\textalpha}, H\textbeta, Mg\textsc{\textalpha}, and/or C\textsc{iv} for 18,100 quasars. Since LAMOST does not have absolute flux calibration information, we obtain the monochromatic continuum luminosities by fitting the SDSS photometric data using the quasar spectra, and then estimate the black hole masses. The catalog and spectra for these quasars are available online. This is the third installment in the series of LAMOST quasar surveys that has released spectra for \sim 43,000 quasars to date. There are 24,772 independently discovered quasars, 17,128 of which are newly discovered. In addition to this great supplement to the new quasar discoveries, LAMOST has also provided a large database (overlapped with SDSS) for investigating quasar spectral variability and discovering unusual quasars, including changing-look quasars, with ongoing and upcoming large surveys.

Key words: catalogs – quasars: general – surveys

Supporting material: machine-readable table

1. Introduction

Quasars, powered by accretion onto the supermassive black holes (SMBHs) residing in the centers of their host galaxies, can emit radiation over a broad range of wavelengths, from radio to \gamma-rays, and are the most luminous, long-lived celestial objects in the universe. They are key ingredients in our understanding of the evolution of galaxies through cosmic time (Kormendy & Ho 2013), and can be used to probe the intergalactic medium, the large-scale structure and the reionization history of the early universe (Becker et al. 2001; Fan et al. 2002, 2006; Ross et al. 2009).

Since the discovery of the first quasar (Schmidt 1963), much effort has been dedicated to increasing the number of quasars (e.g., Schmidt & Green 1983; Hewett et al. 1995; Storrie-Lombardi et al. 1996; Boyle et al. 2000; York et al. 2000). Particularly, the milestone of discovering more than 10\(^\text{5}\) new quasars has been reached thanks to the advent of two large surveys, namely, the Two-Degree Field Quasar Redshift Survey (2dF, Croom et al. 2004) and the Sloan Digital Sky Survey (SDSS, Schneider et al. 2010). With the latest data release of SDSS-IV, the total number of currently known quasars reaches more than half a million (Pàris et al. 2018).

Quasars have distinct colors compared to most stars and normal galaxies (Fan 1999). So the quasar candidates for spectroscopic observations are usually selected based on their multi-color photometric data. In particular, quasars at \(z < 2.2\) have a UV excess that distinguishes them from most stars. For instance, both 2dF and SDSS-I/II select quasar candidates mainly based on UV/optical photometric data in the color–color diagram (Richards et al. 2002; Smith et al. 2005). However, the completeness and efficiency of this method becomes low at \(2.2 < z < 3.5\), especially at \(z = 2.7\) in SDSS, as the stellar locus intersects with the region occupied by quasars in the color–color diagram (Schneider et al. 2007).

To maximize the efficiency of identifying quasars at \(2.2 < z < 3.5\), a lot of improvements have been made. Analogous to the UV excess seen in low-redshift quasars, there is also an excess in the near-infrared K-band for quasars at \(z > 2.2\) compared to stars. A method of selecting quasar candidates at \(z > 2.2\) using K-band excess based on the UKIDSS has been proposed (e.g., Warren et al. 2000; Sharp et al. 2002; Lawrence et al. 2007; Maddox et al. 2008; Small et al. 2008). By combining the optical and infrared photometric data, Wu & Jia (2010) and Wu et al. (2012) proposed effective criteria for selecting quasar candidates based on SDSS/UKIDSS and SDSS/WISE colors. These methods have led to the discovery of more and more intermediate- and high-redshift quasars (e.g., Mortlock et al. 2011; Wu et al. 2013, 2015; Wang et al. 2016).

In recent years, quasar candidates have also been searched using various data-mining algorithms, e.g., the extreme deconvolution method (XDQSO, Bovy et al. 2011), the neural network combinator (Yèche et al. 2010), and the Kernel Density Estimator (KDE, Richards et al. 2004, 2009), which
are adopted by SDSS-III/BOSS (Ross et al. 2012). Recently, Peng et al. (2012) developed a classification system that is made up of several support vector machine (SVM) classifiers, which can be applied to search for quasar candidates from large sky surveys. In addition, variability-based selection (Ross et al. 2012) and cross-matching with X-ray and radio data (Ai et al. 2016) are also performed to supplement identification of quasars.

This paper presents the quasar catalog from the Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) quasar survey conducted between 2015 September and 2017 June. It is the third part in a series of LAMOST quasar survey papers, after data release 1 (DR1, Ai et al. 2016, hereafter Paper I) and data releases 2 and 3 (DR2 and DR3, Dong et al. 2018, hereafter Paper II). In Section 2, we briefly review the candidate selections and the spectroscopic survey. The emission line measurements and black hole mass estimations are described in Sections 3 and 4. Section 5 presents a description of the catalog and the parameters. In Section 6 we provide a summary and a discussion. Throughout this work a $\Lambda$-dominated cosmology is assumed, with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_L = 0.7$, and $\Omega_M = 0.3$.

2. Survey Outline

LAMOST is a quasi-meridian reflecting Schmidt telescope with an effective light-collecting aperture that varies from 3.6 m to 4.9 m (depending on the pointing direction) and a $5^\circ$ field of view in diameter (Wang et al. 1996; Su & Cui 2004; Cui et al. 2012). It has 4000 robotic fibers, with $\sim 3^\circ$ diameter, mounted on its focal plane and connected to 16 spectrographs. Each spectrum of the target is split into two channels, red and blue, and then recorded on red and blue cameras, respectively. The blue channel is optimized for 3700–5900 Å, with 200 Å overlaps between the two channels. The spectral resolution reaches $R \sim 1800$ over the entire wavelength range (see Cui et al. 2012).

After commissioning from 2009 to 2010 and the pilot survey in 2011 (Luo et al. 2012), the LAMOST regular survey was carried out from September 2012 to 2017 June, which was designed to have two major components: the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE) and the LAMOST ExtraGalactic Survey (LEGAS; Zhao et al. 2012). The data are released in yearly increments. The LAMOST quasar survey was conducted under LEGAS, which covers the high Galactic latitude area in the northern sky. The quasar candidates were observed simultaneously with other types of objects from the LEGUE and LEGAS samples during the survey. The typical exposure time for each target is usually $\sim 90$ minutes, which is equally divided into three exposures. The total exposure time would be adjusted according to the observation conditions, e.g., seeing. Although LEGAS used only a small fraction of the total observing time due to the weather conditions and bright sky background, LAMOST has still collected useful data and identified more than 20,000 quasars, half of which are new discoveries, during the first three years. The results of the LAMOST quasar survey as released in DR1, DR2, and DR3 are presented in Paper I and II. In this paper, we present the results of the LAMOST quasar survey conducted in the fourth and fifth years as released in LAMOST data release 4 (DR4) and data release 5 (DR5).

2.1. Target Selection

The details of the method used to select the targets for LAMOST quasar survey can be found in Wu & Jia (2010), Wu et al. (2012), Peng et al. (2012), and Paper I. Here, we briefly review the target selection as follows.

Most of the quasar candidates for spectroscopic follow-up are selected based on the photometry data of SDSS (e.g., Ahn et al. 2012). First, the targets are required to be point sources in SDSS images to avoid large numbers of galaxies. A faint limit of $i = 20$ is adopted to avoid the too low signal-to-noise ratio, and a bright limit of $i = 16$ is adopted to avoid the saturation and the cross-talk of the neighboring fibers. Then, after the correction for Galactic extinction (Schlegel et al. 1998), the SDSS point-spread function (PSF) magnitudes are used in the selection algorithm. The targets are selected mainly based on the following methods:

1. Optical-infrared colors. Although the quasars in redshift of $2.2 < z < 3.5$ have similar optical colors as normal stars, they are usually more luminous in the infrared band (e.g., Warren et al. 2000; Maddox et al. 2008). Thus, distinct optical-infrared colors could be useful tools for selecting quasar candidates. The photometric point sources are cross-matched with the data set from the UKIDSS/Large Area Survey (Lawrence et al. 2007) and WISE all-sky data release$^7$ (Wright et al. 2010). Then, the selection is made according to the location of sources in the multi-dimensional SDSS and UKIDSS/WISE color space (Wu & Jia 2010; Wu et al. 2012). For the UKIDSS-matched sources, quasar candidates are selected with the criteria $Y - K > 0.46(g - z) + 0.82$ or $J - K > 0.45(i - Y - 0.366) + 0.64$ (Wu & Jia 2010), where $Y, J, K$ are in Vega magnitudes and $g, i, z$ are in AB magnitudes. For the WISE-matched sources, the candidates are selected with $w1 - w2 > 0.57$ or $z - w1 > 0.66(g - z) + 2.01$ (Wu et al. 2012), where $w1$ and $w2$ are in Vega magnitudes and $g, z$ are in AB magnitudes.

2. Date-mining algorithms. A mixture of heterogeneous data-mining algorithms, such as SVM (Peng et al. 2012), extreme deconvolution (XD, Bovy et al. 2011), and the kernel-density-estimation technique (KDE, Richards et al. 2004, 2009), are also adopted in combination with the optical-infrared color selection method. We use the same SVM algorithm demonstrated in Peng et al. (2012). The XDQSO sample is identical to that provided by Bovy et al. (2011).

3. Multi-wavelength data matching. In addition to the methods mentioned above, the final input catalog of the targets for the LAMOST quasar survey is also supplemented by cross-matching the SDSS photometry with sources detected in X-ray surveys ($\text{XMM-Newton}$, $\text{Chandra}$, $\text{ROSAT}$) and radio surveys ($\text{FIRST}$, $\text{NVSS}$). The matching radius is 3″ for $\text{FIRST}$, $\text{NVSS}$, $\text{XMM-Newton}$, and $\text{Chandra}$, and 30″ for $\text{ROSAT}$.

In Figure 1, we present the distribution of the $i$-band magnitude and the spectrum signal-to-noise ratio ($S/N$) for the observed quasar candidates in the fourth and fifth years of the LAMOST regular survey. Here, the $S/N$ is calculated as

$^7$ For the WISE data, only sources flagged as unaffected by artifacts in all four bands are used.
the median S/N per pixel in the wavelength regions of 4000–5700 Å and 6200–9000 Å. As can be seen, the distributions of apparent $i$-band magnitude and spectrum S/N peak at $\sim19.4$ mag and $\sim2.5$, respectively.

### 2.2. Quasar Identification

After the observations, the raw data were reduced by the LAMOST 2D pipeline. The final spectrum of each target is produced after procedures including dark and bias subtraction, flat-field correction, spectral extraction, sky subtraction, wavelength calibration, merging sub-exposures, and combining blue and red spectra (see Luo et al. 2015 for details). Next, the spectra were passed to the LAMOST 1D pipeline, which automatically classifies the spectra into four categories according to their object types, namely “STAR,” “GALAXY,” “QSO,” and “Unknown,” and measures the redshift if the spectrum is classified into “GALAXY” or “QSO” (Luo et al. 2015).

In the early data release, only $\sim14\%$ of the observed quasar candidates of the input catalog were identified as QSO, STAR, or GALAXY by pipeline, while the majority of the spectra were classified as “Unknown” (Paper I). One of the main reasons for this was that the magnitude limit of $i = 20$ is too faint for the LAMOST LEGAS survey. The varying seeing due to the site conditions on one hand and the non-classical dome of the telescope on the other hand have significantly affected the spectrum quality (Yao et al. 2012; Luo et al. 2015). As a result, the identification was often limited by the poor quality of the spectrum. This can be clearly seen in DR1 (Paper I), where the pipeline “Unknowns” were on average one magnitude fainter than the pipeline identified ones. The observation conditions in later years have been improved since the first year of regular surveying. In addition, the pipeline has been updated in identifications of the spectra. The pie plots in Figure 2 show the fractions of each type classified by pipeline among the observed quasar candidates. It is apparent that the fraction of “QSO” gets higher and higher in later data releases than in the early data release (Paper I).

We use a Java program ASERA (Yuan et al. 2013) to help visually inspect the observed spectra of quasar candidates, as well as the spectra that are classified as QSO by the 1D pipeline but not in the input catalog of quasar candidates. The misclassified spectra are rejected or re-classified by eye. Each spectrum is inspected by two or three classifiers to check if the features of the spectrum can match the quasar template. We exclude the objects with only narrow emission lines by visual inspection. Finally, the objects identified as a quasar by at least two of the classifiers were included in the final quasar catalog. The redshift of each spectrum is also inspected and estimated according to available typical quasar emission lines. We estimate the redshift based on the peak of one of the emission lines in priority order of $[O\text{III}]\lambda5007$, Mg II, C III, C IV, Hβ and Hα–[N II], when any of them are available. A flag of “ZWARNING = 1” is given when there is only one emission line visible. Finally, there are 19,253 quasars with reliable identifications in DR4 and DR5. Therefore, combining the results in previous data releases (Ai et al. 2016; Dong et al. 2018), the total number of identified quasars during the first five-year regular LAMOST quasar survey reaches 43,102. LAMOST has also performed observations to search for the background quasars in the fields of M31 and M33, which are published elsewhere (e.g., Huo et al. 2010, 2013, 2015, and Z. Y. Huo et al. 2018, in preparation) and will not be included in this paper. Figure 3 shows our identified quasars in the luminosity-redshift space, where the luminosity is indicated using the $K$-corrected $i$-band absolute magnitudes $M_i(z = 2)$, normalized at $z = 2$ (Richards et al. 2006). As can be seen, there is a drop in the redshift distribution at $z \sim 1.0$ for DR4 and DR5, similar to the results of previous LAMOST quasar data releases (Paper I and II). The drop comes from the inefficient identification of quasars in this redshift range when the Mg II emission line moves around the overlapping wavelength region ($\sim6000\,\text{Å}$) between the blue and red channels. The LAMOST quasar candidates were required to be point sources in our target selection (Section 2.1). It has been found that a significant fraction of quasars can be resolved up to $z \sim 0.6$ in SDSS (e.g., Matsuoka et al. 2014). Thus, the LAMOST quasar sample may suffer from incompleteness at low redshift, $z \lesssim 0.6$.

Among the 19,253 identified quasars in DR4 and DR5, 11,097 are known ones in the SDSS DR14 quasar catalog (Pâris et al. 2018) or NED8 or the Half Million Quasars catalog (Flesch 2015), while the remaining 8162 are newly discovered quasars by LAMOST. For the sources both observed in SDSS and LAMOST, only 119 of them have redshift differences $|\Delta z| = |z_{\text{LAMOST}} - z_{\text{SDSS}}| > 0.1$. We have visually checked the spectra of these sources and find that the differences arise from the misidentification of the redshift for LAMOST spectra. For the other objects, the uncertainty of the redshift may arise for two reasons. First, we estimate the redshift based on one of the typical quasar emission lines in priority orders, while SDSS redshift is based on the result of a principal component analysis and the peak of the Mg II emission line (Pâris et al. 2018). In this case, sources of uncertainty could be line shifts relative to one another or line asymmetries. These cases are rare and deserve individual investigations. Second, the low S/N spectra also affect the estimation of redshift. In Figure 4, we plot the redshift differences between LAMOST and SDSS as a function of LAMOST spectrum S/N. A increasing trend of $|\Delta z|$ with

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8 http://ned.ipac.caltech.edu/
decreasing S/N can be clearly seen, indicating that low S/N could be a reason for the redshift uncertainties.

As a large number of quasars in SDSS have also been observed by LAMOST, with time intervals of months to decades between the SDSS and LAMOST survey, it is suitable to use SDSS and LAMOST observations to study the quasar spectral variability on both short and long timescales. For instance, it provides a large database for searching changing-look AGNs, which shows the appearance or disappearance of their broad emission lines (e.g., MacLeod et al. 2016; McElroy et al. 2016). Actually, LAMOST has already produced many new discoveries of these types of rare objects (Yang et al. 2018). In Figure 5 we present one such example of changing-look AGNs discovered by comparing LAMOST and SDSS observations.

3. Spectral Analysis

Here and in the following sections we describe the spectral analysis, the measurements of typical quasar emission lines, and the estimations of black hole masses. We note that LAMOST is only equipped with a spectrograph and cannot provide photometric information for the observed targets. Thus, only relative flux calibration has been applied to the released LAMOST spectra. In addition, it is difficult to find a suitable flux standard star for each spectrograph during the observations of our extragalactic targets because they are faint and located at high Galactic latitudes. So the flux calibration is very poor for these targets due to the low S/N. Therefore, we use the SDSS photometric data to estimate the continuum luminosity (see Section 4).

We fit the spectra based on IDL routines in the MPFIT package (Markwardt 2009), which performs $\chi^2$ minimization using the Levenberg–Marquardt method. Before the fitting, each spectrum is corrected for Galactic extinction using the reddening map of Schlegel et al. (1998) with an extinction curve of $R_V = 3.1$ (Fitzpatrick 1999), and then transformed into the rest-frame of the object using the visually inspected redshift.

First, a broken power law is fitted to the spectrum in the wavelength windows of [1350, 1365] Å, [1450, 1465] Å, [1690,
LAMOST spectra

Vanden Berk et al. primarily chose to avoid the strong quasar emission lines listed in step, a local pseudo-continuum, i.e., a simple power law or a composite quasar spectra in Vanden Berk et al. at rest-frame, which is similar to the value derived from the mean black hole mass estimators and are the strongest broad emission lines in the available spectral range for most of the sources. The FeII template from Véron-Cetty et al. is modeled by two Gaussians, one for a line core and the other for a blueshifted wing component, and they are not tied to the Hβ narrow component. The profile and redshift of each line of the [O III] λλ4959,5007 doublet is tied during the fitting and their flux ratio is fixed at a theoretical value of 1:3.

For the Hα, the same pseudo-continuum is applied to fit the spectrum in windows of [6000, 6250] Å and [6800, 7000] Å. The normalization and the index of the power law are set to be free, while the parameters of the FeII template are fixed at the best-fit values obtained from the Hβ fitting. We model the pseudo-continuum-subtracted Hα–[N II]–[S II] emission lines in the spectral range of [6350, 6800] Å using Gaussian profiles. The broad component of Hα is modeled by two Gaussians, whereas [N II]λλ6548,6584, [S II]λλ6716,6731, and the narrow Hα component are modeled by a single Gaussian profile.

The upper limits of the FWHM for the narrow lines are set to be $900 \text{ km s}^{-1}$. The profile and redshift of the narrow lines are tied to each other and the relative flux ratio of [N II] λλ6548,6584 doublet is fixed at 2.96. Examples of the best-fitting results are given in Figure 6.

3.2. Mg II

Fittings of the Mg II and C IV emission lines are sometimes affected by the absorption features. Similar to Paper I, in order to reduce the effect of narrow absorption features, we mask out 3σ outliers below the 20 pixel boxcar-smoothed spectrum when fitting Mg II and C IV emission lines.

We fit the Mg II emission line for objects at $0.4 \lesssim z \lesssim 2.0$. A pseudo-continuum consisting of a simple power law and ultraviolet Fe II multiplet are used to fit the spectrum in the range of [2500, 2700] Å and [2900, 3090] Å. The Fe II multiplet beneath the Mg II is modeled with a semi-empirical template generated by Tsuzuki et al. (2006). The best-fit pseudo-continuum is subtracted from the spectrum. Then we fit the Mg IIλλ2796,2803 doublet using a similar model as in Wang et al. (2009). Each of the narrow components is modeled with a single Gaussian profile. The upper limit of FWHM is set to be $900 \text{ km s}^{-1}$. The width and redshift of the narrow lines are tied to each other. The flux ratio is constrained between 2:1 and 1:1 (Laor et al. 1997). Each of the broad components is modeled by a truncated five-parameter Gauss–Hermite series (van der Marel & Franx 1993; see also Salvati et al. 2007). The profile, redshift, and flux ratio of two broad components...
are constrained following the same prescription used for the narrow components. Examples of the best-fitting results are given in the left panel of Figure 7.

### 3.3. C IV

We fit the C IV emission line for objects at $1.8 \leq z \leq 4.3$. Only a simple power law is fitted to the spectrum in the range of [1445, 1465] Å and [1690, 1705] Å as the pseudo-continuum because the Fe II multiplet underneath C IV is very weak and it was found that fitting C IV without subtraction of Fe II does not change the FWHM of C IV significantly (Shen et al. 2011, hereafter S11). After subtracting the best-fit continuum from the spectrum, a Gauss–Hermite series and single Gaussian profile were used to model the broad and narrow components, respectively. Similar to the fitting procedure in Paper I, we do not set the upper limit for the FWHM of the narrow component, as there are still debates on whether or not a strong narrow component exists for the C IV line (Baskin & Laor 2005). Examples of the best-fitting results are given in the right panel of Figure 7.

### 3.4. Reliability of the Fittings and Error Estimation

After the automatic procedure, we inspect the fitting results visually for each object, pick out the bad fittings, and fine-tune the fitting procedures. Finally, the results are acceptable for most of the spectra with high S/N. The bad fittings are mainly caused by low S/N or a lack of good pixels. For each line, a flag of LINE_FLAG = 0 is given to indicate an acceptable fitting and reliable measurement, while LINE_FLAG = -1 indicates a spurious measurement. We note that a emission line is not fitted when the fitting wavelength range is not fully
covered by the observed wavelength range, or when there are not enough good pixels ($n_{\text{pixel}} < 100$) due to bad quality of the spectrum, or when the fitting wavelength range of the line is redshifted to the overlapping region between the blue and red channels. In this case, we set $\text{LINE}_\text{FLAG} = -9999$. The broad absorption features at Mg II and C IV also affect some of the fitting results. We give a flag of BAL_FLAG to indicate whether broad absorption features are present in the spectra by visual inspection.

In Figures 8 and 9 we plot a comparison between our fitting results and those of S11 for 5974 overlapped sources. As can be seen from the normalized distribution of $\log(\text{FWHM}_{\text{LAMOST}}/\text{FWHM}_{\text{S11}})$ for broad H\o (upper left), broad H\beta (upper right), broad Mg II (lower left), and total C IV (lower right) emission lines, respectively. The Spearman correlation coefficient $\rho$, p-values, mean value of the distribution, and its standard deviation are also tabulated in the corresponding plots. Only the spectra with reliable fits ($\text{LINE}_\text{FLAG} = 0$) are considered.

Figure 8. Comparison between the measurements of the line width in this work and in Shen et al. (2011). We show the plot of $\log(\text{FWHM}_{\text{LAMOST}}/\text{FWHM}_{\text{S11}})$ vs. the median S/N per pixel in line-fitting region and the normalized distribution of $\log(\text{FWHM}_{\text{LAMOST}}/\text{FWHM}_{\text{S11}})$ for broad H\o (upper left), broad H\beta (upper right), broad Mg II (lower left), and total C IV (lower right) emission lines, respectively. The Spearman correlation coefficient $\rho$, p-values, mean value of the distribution, and its standard deviation are also tabulated in the corresponding plots. Only the spectra with reliable fits ($\text{LINE}_\text{FLAG} = 0$) are considered.

Figure 9. Same as Figure 8, but for comparison between the measurements of equivalent width in this work and in Shen et al. (2011).

Figure 10. Normalized distributions of the median S/N per pixel around the line-fitting regions for objects with line measurements. Only the spectra with reliable fits ($\text{LINE}_\text{FLAG} = 0$) are considered.

Another possible reason is the different S/Ns. Figure 10 shows the normalized distributions of the median S/N per pixel in line-fitting regions for quasars in LAMOST DR4 and DR5. The peak of the distributions are all around or below S/N = 5.
We compare the median S/N per pixel of the line-fitting regions for the overlapped sources in LAMOST DR4 and DR5 and S11 in Figure 11. The normalized distributions of log(S/N)\textsubscript{LAMOST} − log(S/N)\textsubscript{S11} show that our spectra have significantly lower S/Ns than those in S11 for the same object. To explore the impact of S/N on our fitting results, we also show the plots of log(LAMOST/S11) versus the median S/N per pixel in line-fitting regions. In Figure 8, a trend of decreasing log(FWHM\textsubscript{LAMOST}/FWHM\textsubscript{S11}) with decreasing S/N is demonstrated by a Spearman correlation test (ρ > 0), although this trend is not significant for Hα and Mg II. In Figure 9, a trend of decreasing log(EW\textsubscript{LAMOST}/EW\textsubscript{S11}) with increasing S/N is demonstrated (ρ < 0) for Hα, Mg II, and C IV.

The simulation by S11 anticipates that the measured FWHMs and EWs are biased by less than ±20% for high-EW objects as S/N decreases, while the FWHMs and EWs are biased low/high by >20% as S/N decreases. However, the exact dependences of FWHMs and EWs on spectrum S/N are probably more complicated and need further explorations in the future.

To estimate the errors of the measured FWHM and EW for the broad emission lines, we assume that the measured quantities of each component of the broad emission lines follow the Gaussian distribution, of which the standard deviation is the uncertainty obtained from χ² minimization. We randomly generate each component and measure the FWHM and EW of the profile created by combining these components. The process was repeated 1000 times and the uncertainties of FWHM and EW for the broad emission line were estimated from the 68% range of the distributions. For the narrow emission lines, the errors of the measurement are obtained from the χ² minimization.

4. Continuum Luminosity and Virial Black Hole Mass

In order to estimate the continuum luminosity for LAMOST quasars, we use the SDSS ugriz-band photometry following the procedures in Papers I and II. First, we cross-match LAMOST DR4/DR5 quasars with the SDSS photometric database with a 2″-matching radius. We extract the PSF magnitudes, correct them for Galactic extinction, and convert them into the flux densities F\lambda at the effective wavelength of each filter. Next, we fit the five flux densities in the rest-frame with a quasar spectrum model that is composed of a broken power-law continuum emission and line emission made from the composite quasar spectra in Vanden Berk et al. (2001). During the fitting, the break of the broken power laws is fixed at 4661 Å and the normalization of the power laws is tied to the mean value of emission in ranges of [1350–1365]Å and [4200–4230]Å (Paper I). The indices of the power laws and the normalization of the line emission are set as free parameters. As a result, the average power-law indices from the best fits are found to be <α\textsubscript{u}> = -0.40, <α\textsubscript{g} > = -1.60 blueward of 4661 Å and <α\textsubscript{r} > = -1.65, <α\textsubscript{i} > = -0.35 redward of 4661 Å, which is in good agreement with those of the median composite spectra in Vanden Berk et al. (2001). Examples of the fitting results are presented in Figure 12.

The monochromatic continuum luminosities at 1350, 3000, and 5100 Å are calculated from the best-fit power-law continuum, which can be used as a proxy for the radius of the broad emission line region. Meanwhile, with the broad line width as a proxy for the virial velocity, the black hole masses can be estimated based on the empirical scaling relations between the virial black hole mass, the FWHM of the primary emission lines and the corresponding continuum luminosities, which are calibrated using local AGNs with reverberation mapping masses (e.g., McLure & Dunlop 2004; Vestergaard & Peterson 2006;
Wang et al. 2009). Here, we estimate the virial black hole masses using the relations

$$
\log M_{\text{BH}} = 
\log \left( \frac{\text{FWHM}(\text{H}\beta)}{\text{km s}^{-1}} \right)^{2} \left( \frac{L_{5100}}{10^{44} \text{ erg s}^{-1}} \right)^{0.5} + 0.91
$$

(1)

for H\beta-based estimates (Vestergaard & Peterson 2006),

$$
\log M_{\text{BH}} = 
\log \left( \frac{\text{FWHM}(\text{Mg II})}{\text{km s}^{-1}} \right)^{1.51} \left( \frac{L_{3000}}{10^{44} \text{ erg s}^{-1}} \right)^{0.5} + 2.60
$$

(2)

for Mg II-based estimates (Wang et al. 2009), and

$$
\log M_{\text{BH}} = 
\log \left( \frac{\text{FWHM}(\text{C IV})}{\text{km s}^{-1}} \right)^{2} \left( \frac{L_{1350}}{10^{44} \text{ erg s}^{-1}} \right)^{0.53} + 0.66
$$

(3)

for the C IV-based estimates (Vestergaard & Peterson 2006). The FWHM of broad H\beta, broad Mg II, and whole C IV line are used during the estimations.

Although it is straightforward to calculate the black hole mass using the above relations, one should bear in mind the large uncertainties of the estimates ($\gtrsim 0.4$ dex, e.g., Vestergaard & Peterson 2006; Wang et al. 2009). Figure 13 shows the distribution of the black hole masses with redshifts. It is apparent that mass estimates for the LAMOST quasars occupy the same area as those of SDSS DR7 quasars from S11. We also note that our estimations adopt the continuum luminosities obtained from the SDSS photometry more than 10 years before the LAMOST survey, which introduce additional uncertainties because the ultraviolet/optical emission of quasars varied, generally with magnitudes of 0.1–0.2 mag. To justify this effect, for the overlapped objects in LAMOST DR4&5 and S11, we compare our estimates of continuum luminosities and black hole masses with those estimated by S11 in Figure 14. It is shown that our estimates are in general agreement with S11’s results, though with systematically lower values than S11. The lower value of black hole mass may be driven by the lower S/N, leading to smaller line width, as mentioned in Section 3.4.

5. Description of the Catalog

We give a compiled catalog for the quasars identified in LAMOST DR4 and DR5 along with this paper. The keyword for each column is listed in Table 1 and described as below.

1. Unique spectra ID.
2. Target Observation date.
3. LAMOST DR4&5 object name: Jhhmmss.ss+ddmmss.s (J2000).
4. R.A. and decl. (in decimal degrees, J2000).
5. Information of the spectroscopic observation: modified Julian date (MJD), spectroscopic plan name (PlanID), spectrograph identification (spID), and spectroscopic fiber number (fiberID). These four numbers are unique for each spectrum named in the format of spec–MJD–planID_spID–fiberID.fits.
6. Redshift and its flag based on visual inspections. 1 = not robust.
7. Target selection flag. This flag is a four-character string indicating how the quasar candidate is selected, in which the value of each character is a boolean value, i.e., “1” is truth and “0” is false. The first character indicates infrared-optical color selection. The second character indicates data-mining selection. The third character indicates selection based on X-ray detection. The fourth character indicates selection based on radio detection. A entry with SOURCE_FLAG = “1101” indicates that the
| Column | Name               | Format | Description                                                                                                                                 |
|--------|--------------------|--------|--------------------------------------------------------------------------------------------------------------------------------------------|
| 1      | ObsID              | LONG   | Unique Spectra ID                                                                                                                             |
| 2      | ObsDate            | STRING | Target observation date                                                                                                                     |
| 3      | NAME               | STRING | LAMOST designation hhmmss:ss+ddmms (J2000)                                                                                                  |
| 4      | R.A.               | DOUBLE | R.A. in decimal degrees (J2000)                                                                                                             |
| 5      | Decel              | DOUBLE | Decl. in decimal degrees (J2000)                                                                                                            |
| 6      | LMJD               | LONG   | Local Modified Julian Day of observation                                                                                                   |
| 7      | PLANID             | STRING | Spectroscopic plan name                                                                                                                     |
| 8      | SPID               | LONG   | Spectrograph identification                                                                                                                 |
| 9      | FIBERID            | LONG   | Spectroscopic fiber number                                                                                                                  |
| 10     | Z_VI               | DOUBLE | Redshift from visual inspection                                                                                                              |
| 11     | ZWARNING           | LONG   | ZWARNING flag from visual inspection                                                                                                          |
| 12     | SOURCE_FLAG        | STRING | Target selection flag                                                                                                                       |
| 13     | M1_Z2              | DOUBLE | $M_1 \times (z=2)$, K-corrected to $z=2$ following Richards et al. (2006)                                                                   |
| 14     | NSPECDB            | LONG   | Number of spectroscopic observations                                                                                                        |
| 15     | SNR_SPEC           | DOUBLE | Median S/N per pixel of the spectrum                                                                                                        |
| 16     | BAL_FLAG           | DOUBLE | Flag of broad absorption features                                                                                                           |
| 17     | FWHM_BROAD_HA      | DOUBLE | FWHM of broad H$\alpha$ in km s$^{-1}$                                                                                                     |
| 18     | ERR_FWHM_BROAD_HA  | DOUBLE | Uncertainty in FWHM$_{H\alpha,\text{broad}}$                                                                                               |
| 19     | EW_BROAD_HA        | DOUBLE | Rest-frame equivalent width of broad H$\alpha$ in Å                                                                                         |
| 20     | ERR_EW_BROAD_HA    | DOUBLE | Uncertainty in EW$_{H\alpha,\text{broad}}$                                                                                                 |
| 21     | FWHM_NARROW_HA     | DOUBLE | FWHM of narrow H$\alpha$ in km s$^{-1}$                                                                                                     |
| 22     | ERR_FWHM_NARROW_HA | DOUBLE | Uncertainty in FWHM$_{H\alpha,\text{narrow}}$                                                                                              |
| 23     | EW_NARROW_HA       | DOUBLE | Rest-frame equivalent width of narrow H$\alpha$ in Å                                                                                       |
| 24     | ERR_EW_NARROW_HA   | DOUBLE | Uncertainty in EW$_{H\alpha,\text{narrow}}$                                                                                                 |
| 25     | EW_NII_6584        | DOUBLE | Rest-frame equivalent width of [N II]$_{\lambda6584}$ in Å                                                                                |
| 26     | ERR_EW_NII_6584    | DOUBLE | Uncertainty in EW$_{[\text{N II}]_{\lambda6584}}$                                                                                           |
| 27     | EW_SII_6716        | DOUBLE | Rest-frame equivalent width of [S II]$_{\lambda6716}$ in Å                                                                                 |
| 28     | ERR_EW_SII_6716    | DOUBLE | Uncertainty in EW$_{[\text{S II}]_{\lambda6716}}$                                                                                           |
| 29     | EW_SII_6731        | DOUBLE | Rest-frame equivalent width of [S II]$_{\lambda6731}$ in Å                                                                                 |
| 30     | ERR_EW_SII_6731    | DOUBLE | Uncertainty in EW$_{[\text{S II}]_{\lambda6731}}$                                                                                           |
| 31     | EW_FE              | DOUBLE | Rest-frame equivalent width of Fe within 6000–6500 Å                                                                                       |
| 32     | LINENPIX_HA        | LONG   | Number of good pixels for the rest-frame 6400–6765 Å                                                                                      |
| 33     | LINE_MED_SN_HA     | DOUBLE | Median S/N per pixel for the rest-frame 6400–6765 Å                                                                                       |
| 34     | LINE_FLAG_HA       | LONG   | Flag for the quality in H$\alpha$ fitting                                                                                                   |
| 35     | FWHM_BROAD_HB      | DOUBLE | FWHM of broad H$\beta$ in km s$^{-1}$                                                                                                       |
| 36     | ERR_FWHM_BROAD_HB  | DOUBLE | Uncertainty in FWHM$_{H\beta,\text{broad}}$                                                                                               |
| 37     | EW_BROAD_HB        | DOUBLE | Rest-frame equivalent width of broad H$\beta$ in Å                                                                                         |
| 38     | ERR_EW_BROAD_HB    | DOUBLE | Uncertainty in EW$_{H\beta,\text{broad}}$                                                                                                 |
| 39     | FWHM_NARROW_HB     | DOUBLE | FWHM of narrow H$\beta$ in km s$^{-1}$                                                                                                      |
| 40     | ERR_FWHM_NARROW_HB | DOUBLE | Uncertainty in FWHM$_{H\beta,\text{narrow}}$                                                                                               |
| 41     | EW_NARROW_HB       | DOUBLE | Rest-frame equivalent width of narrow H$\beta$ in Å                                                                                       |
| 42     | ERR_EW_NARROW_HB   | DOUBLE | Uncertainty in EW$_{H\beta,\text{narrow}}$                                                                                                 |
| 43     | FWHM_OIII_5007     | DOUBLE | FWHM of [O III]$_{\lambda5007}$ in km s$^{-1}$                                                                                              |
| 44     | ERR_FWHM_OIII_5007 | DOUBLE | Uncertainty in FWHM$_{[\text{O III}]_{\lambda5007}}$                                                                                       |
| 45     | EW_OIII_5007       | DOUBLE | Rest-frame equivalent width of [O III]$_{\lambda5007}$ in Å                                                                                 |
| 46     | ERR_EW_OIII_5007   | DOUBLE | Uncertainty in EW$_{[\text{O III}]_{\lambda5007}}$                                                                                         |
| 47     | EW_FE              | DOUBLE | Rest-frame equivalent width of Fe within 4435–4685 Å                                                                                       |
| 48     | LINENPIX_HB        | LONG   | Number of good pixels for the rest-frame 4750–4950 Å                                                                                      |
| 49     | LINE_MED_SN_HB     | DOUBLE | Median S/N per pixel for the rest-frame 4750–4950 Å                                                                                       |
| 50     | LINE_FLAG_HB       | LONG   | Flag for the quality in H$\beta$ fitting                                                                                                    |
| 51     | FWHM_MGII          | DOUBLE | FWHM of the whole Mg II emission line in km s$^{-1}$                                                                                         |
| 52     | ERR_FWHM_MGII      | DOUBLE | Uncertainty in FWHM$_{\text{Mg II,whole}}$                                                                                                 |
| 53     | EW_MGII            | DOUBLE | Rest-frame equivalent width of the whole Mg II in Å                                                                                         |
| 54     | ERR_EW_MGII        | DOUBLE | Uncertainty in EW$_{\text{Mg II,whole}}$                                                                                                   |
| 55     | FWHM_BROAD_MGII    | DOUBLE | FWHM of the whole broad Mg II in km s$^{-1}$                                                                                                 |
| 56     | ERR_FWHM_BROAD_MGII| DOUBLE | Uncertainty in FWHM$_{\text{Mg II,broad}}$                                                                                                 |
| 57     | EW_BROAD_MGII      | DOUBLE | Rest-frame equivalent width of the whole broad Mg II in Å                                                                                   |
| 58     | ERR_EW_BROAD_MGII  | DOUBLE | Uncertainty in EW$_{\text{Mg II,broad}}$                                                                                                   |
| 59     | FWHM_BROAD_MGII_2796| DOUBLE | FWHM of the broad Mg II$_{\lambda2796}$ in km s$^{-1}$                                                                                   |
| 60     | ERR_FWHM_BROAD_MGII_2796| DOUBLE | Uncertainty in FWHM$_{\text{Mg II,\lambda2796,broad}}$                                                                                   |
| 61     | FWHM_NARROW_MGII_2796| DOUBLE | FWHM of the narrow Mg II$_{\lambda2796}$ in km s$^{-1}$                                                                                   |
Table 1
(Continued)

| Column       | Name                          | Format   | Description                                                                 |
|--------------|-------------------------------|----------|------------------------------------------------------------------------------|
| 62           | ERR_FWHM_NARROW_MGII_2796     | DOUBLE   | Uncertainty in FWHM_{MgII2796,narrow}                                        |
| 63           | EW_FE_MGII                    | DOUBLE   | Rest-frame equivalent width of Fe within 2200–3000 Å in Å                   |
| 64           | LINE_NPIX_MGII                | LONG     | Number of good pixels for the rest-frame 2700–2900 Å                        |
| 65           | LINE_MED_SN_MGII              | DOUBLE   | Median $S/N$ per pixel for the rest-frame 2700–2900 Å                       |
| 66           | LINE_FLAG_MGII                | LONG     | Flag for the quality in Mg II fitting                                        |
| 67           | FWHM_CIV                      | DOUBLE   | FWHM of the whole C IV in km s$^{-1}$                                         |
| 68           | ERR_FWHM_CIV                  | DOUBLE   | Uncertainty in FWHM_{C IV,whole}                                            |
| 69           | EW_CIV                        | DOUBLE   | Rest-frame equivalent width of the whole C IV in Å                           |
| 70           | ERR_EW_CIV                    | DOUBLE   | Uncertainty in EW_{C IV,whole}                                              |
| 71           | FWHM_BROAD_CIV                | DOUBLE   | FWHM of the broad C IV in km s$^{-1}$                                        |
| 72           | ERR_FWHM_BROAD_CIV            | DOUBLE   | Uncertainty in FWHM_{C IV,broad}                                            |
| 73           | EW_BROAD_CIV                  | DOUBLE   | Rest-frame equivalent width of the broad C IV in Å                          |
| 74           | ERR_EW_BROAD_CIV              | DOUBLE   | Uncertainty in EW_{C IV,broad}                                              |
| 75           | FWHM_NARROW_CIV               | DOUBLE   | FWHM of the narrow C IV in km s$^{-1}$                                       |
| 76           | ERR_FWHM_NARROW_CIV           | DOUBLE   | Uncertainty in FWHM_{C IV,narrow}                                           |
| 77           | EW_NARROW_CIV                 | DOUBLE   | Rest-frame equivalent width of the narrow C IV in Å                         |
| 78           | ERR_EW_NARROW_CIV             | DOUBLE   | Uncertainty in EW_{C IV,narrow}                                             |
| 79           | LINE_NPIX_CIV                 | LONG     | Number of good pixels for the rest-frame 1500–1600 Å                       |
| 80           | LINE_MED_SN_CIV               | DOUBLE   | Median $S/N$ per pixel for the rest-frame 1500–1600 Å                      |
| 81           | LINE_FLAG_CIV                 | LONG     | Flag for the quality in C IV fitting                                        |

| 82           | ALPHA_LAMBDA_1                | DOUBLE   | Wavelength power-law index from ~1300 to 4661 Å                            |
| 83           | ALPHA_LAMBDA_2                | DOUBLE   | Wavelength power-law index redward of 4661 Å                               |
| 84           | MODEL_PHOT_REDCHI2            | DOUBLE   | Reduced chi-square                                                          |
| 85           | LOGL5100                      | DOUBLE   | Monochromatic luminosity at 5100 Å in erg s$^{-1}$                         |
| 86           | LOGL3000                      | DOUBLE   | Monochromatic luminosity at 3000 Å in erg s$^{-1}$                         |
| 87           | LOGL1350                      | DOUBLE   | Monochromatic luminosity at 1350 Å in erg s$^{-1}$                         |
| 88           | LOGBH_HB                      | DOUBLE   | Virial BH mass ($M_\odot$) based on H$\beta$                              |
| 89           | LOGBH_MgII                    | DOUBLE   | Virial BH mass ($M_\odot$) based on Mg II                                  |
| 90           | LOGBH_CIV                     | DOUBLE   | Virial BH mass ($M_\odot$) based on C IV                                   |
| 91           | SDSS_NAME                     | STRING   | Name of the quasar in the SDSS quasar catalog (Pâris et al. 2018)           |
| 92           | 2RXS_NAME                     | STRING   | Name of the object in the 2nd ROSAT all-sky survey point source catalog (2RXS, Boller et al. 2016) |
| 93           | 2RXS_CTS                      | DOUBLE   | Background-corrected source counts in 0.1–2.4 keV from 2RXS source catalog |
| 94           | 2RXS_CTS                      | DOUBLE   | Error of the source counts from 2RXS source catalog                        |
| 95           | 2RXS_EXPTIME                  | DOUBLE   | Source exposure time from 2RXS source catalog                               |
| 96           | LM_2RXS_SEP                   | DOUBLE   | LAMOST-2RXS separation in arcsec                                           |
| 97           | 3XMM_NAME                     | STRING   | Name of the object in XMM-Newton Serendipitous Source Catalog (3XMM-DR8, Rosen et al. 2016) |
| 98           | 3XMM_FLUX                     | DOUBLE   | Flux in 0.2–12.0 keV band from 3XMM-DR8 (in erg s$^{-1}$ cm$^{-2}$)         |
| 99           | 3XMM_FLUX_ERR                 | DOUBLE   | Error of the flux in 0.2–12.0 keV band from 3XMM-DR8 (in erg s$^{-1}$ cm$^{-2}$) |
| 100          | LM_3XMM_SEP                   | DOUBLE   | LAMOST-3XMM separation in arcsec                                           |
| 101          | FPEAK                         | DOUBLE   | FIRST peak flux density at 20 cm in mJy                                      |
| 102          | LM_FIRST_SEP                  | DOUBLE   | LAMOST-FIRST separation in arcsec                                           |

(This table is available in its entirety in machine-readable form.)

quasar was selected by its infrared-optical color, data-mining algorithms and radio detection. A entry with SOURCE_FLAG = “0000” means the object is not included in LAMOST LEGAS quasar survey sample but identified as quasar.

8. $M(z = 2)$: absolute $i$-band magnitude. $K$-corrected to $z = 2$ following Richards et al. (2006).

9. Number of spectroscopic observations for the quasar.
   When there is more than one observation for the object, the line properties are obtained from only one of the observations in which the fiber pointing position is nearest to the position in our quasar candidate catalog.

10. Median $S/N$ per pixel in the wavelength regions of [4000–5700] Å and [6200, 9000] Å.

11. Flag of broad absorption features. BAL_FLAG = 1 indicates broad absorption features are present.

12. FWHM, rest-frame equivalent width, and their uncertainties, for broad H$\alpha$, narrow H$\alpha$, [N II],6584, [S II] $\lambda\lambda6716,6731$ emission lines.

13. Rest-frame equivalent width of iron emissions in 6000–6500 Å.

14. Number of good pixels and median $S/N$ per pixel for the spectrum in the region of rest-frame 6400–6765 Å.

15. Flag indicates reliability of the emission line-fitting results in H$\alpha$ region upon visual inspections. 0 = reliable; −1 = unreliable. This value is set to be −9999 if H$\alpha$ is not measured due to a lack of good pixels in the fitting wavelength region.
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16. FWHM, rest-frame equivalent width, and their uncertainties, for broad H β, narrow H β, [O III]λλ5007 emission lines.

17. Number of good pixels and median S/N per pixel for the spectrum in region of rest-frame 4750–4950 Å.

18. Flag indicates reliability of the emission line-fitting results in H β region upon visual inspections. 0 = reliable; −1 = unreliable. This value is set to be −9999 if H β is not measured due to a lack of good pixels in the fitting wavelength region.

19. FWHM, rest-frame equivalent width, and their uncertainties, for the whole Mg II emission line.

20. FWHM, rest-frame equivalent width, and their uncertainties, for the broad Mg II emission line.

21. FWHM, rest-frame equivalent width, and their uncertainties, of the total broad Mg II emission line.

22. FWHM and its uncertainties of the broad and narrow Mg II λ2796 emission lines.

23. Rest-frame equivalent width of iron emissions in 4685–4435 Å.

24. Number of good pixels and median S/N per pixel for the spectrum in regions of rest-frame 2700–2900 Å.

25. Flag indicates reliability of the emission line-fitting results in the Mg II region upon visual inspections. 0 = reliable; −1 = unreliable. This value is set to be −9999 if Mg II is not measured due to a lack of good pixels in the fitting wavelength region.

26. FWHM, rest-frame equivalent width, and their uncertainties, of the whole C IV emission line.

27. FWHM, rest-frame equivalent width, and their uncertainties, of the broad C IV emission line.

28. FWHM, rest-frame equivalent width, and their uncertainties, of the narrow C IV emission line.

29. Number of good pixels and median S/N per pixel for the spectrum in the region of rest-frame 1500–1600 Å.

30. Flag indicates reliability of the emission line-fitting results in the C IV region upon visual inspections. 0 = reliable; −1 = unreliable. This value is set to be −9999 if C IV is not measured due to a lack of good pixels in the fitting wavelength region.

31. Wavelength power-law index, αλ, from ~1300 to 4661 Å.

32. Wavelength power-law index, αλ, from ~redward of 4661 Å.

33. Reduced chi-squared in SDSS photometry modeling; −9999 if not fitted.

34. Monochromatic luminosities at 5100, 3000, and 1350 Å.

35. Virial black hole masses (in $M_\odot$) based on H β, Mg II, and C IV.

36. Name of the quasar in the SDSS quasar catalog. The LAMOST DR4 and DR5 quasar catalog was cross-correlated with the SDSS quasar catalog (DR14, Páris et al. 2018) using a matching radius of 3″.

37. Name of the object in the 2nd ROSAT all-sky survey point source catalog (2RXS, Boller et al. 2016). The LAMOST DR4&5 quasar catalog was cross-correlated with 2nd ROSAT all-sky survey point source catalog using a matching radius of 30″. The nearest point source in 2RXS was chosen.

38. The background-corrected source counts in the full band (0.1–2.4 keV), and its error, from the 2nd ROSAT all-sky survey point source catalog (Boller et al. 2016).

39. The exposure time of the ROSAT measurement.

40. Angular separation between the LAMOST and ROSAT source positions.

41. Name of the object in the XMM-Newton Serendipitous Source Catalog (3XMM-DR8, Rosen et al. 2016). The LAMOST DR4&5 quasar catalog was cross-correlated with the XMM-Newton Serendipitous Source Catalog using a matching radius of 3″.

42. The mean full-band (0.2–12 keV) flux, and its error, from the XMM-Newton Serendipitous Source Catalog (Rosen et al. 2016).

43. Angular separation between the LAMOST and 3XMM-DR8 source positions.

44. FIRST peak flux density at 20 cm in units of mJy. The LAMOST DR4&5 quasar catalog was cross-correlated with the FIRST survey catalog using a matching radius of 5″.

45. Angular separation between LAMOST and the FIRST source positions.

6. Summary

In this paper, we present the results of the LAMOST quasar survey in the 4th and 5th data releases obtained from observations that began on 2015 September and September 2016, respectively. There are a total of 19,253 visually confirmed quasars. The catalog and spectra of these quasars will be available online. Among these identified quasars, 11,458 were independently discovered by LAMOST, 3296 of which were reported in the SDSS DR12/14 quasar catalog (Páris et al. 2017, 2018) after the survey began, while the other 8162 are new discoveries of LAMOST that have not been reported before (see Figure 15). After the first five-year regular observation, the total number of identified quasars in the LAMOST quasar survey reaches 43,102. Nearly half of them are newly discovered.

In this work, we provide Hα, H β, Mg II, and C IV emission line properties (FWHM and equivalent width) for each quasar.
spectrum by performing spectral analysis. Although LAMOST is not equipped with a photometry instrument and lacks information on the absolute flux calibration for the spectra, we obtain the continuum luminosity underneath the emission lines and the corresponding black hole masses by fitting the SDSS photometric data using the quasar spectra.

In addition to being a great supplement for low-to-moderate redshift quasar discoveries, LAMOST also provides a large database for investigating the quasar spectral variabilities, as LAMOST and SDSS observations were taken over a roughly 10 year baseline. By comparing the LAMOST and SDSS data, more unusual quasars, including changing-look AGNs (Yang et al. 2018) or tidal disruption events (Liu et al. 2018), may be discovered.

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Facility: LAMOST.

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