

LETTERS

## Quasars in the Galactic Anti-Center Area from LAMOST DR3

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**Abstract** We present a sample of quasars discovered in an area near the Galactic Anti-Center covering  $150^\circ \leq l \leq 210^\circ$  and  $|b| \leq 30^\circ$ , based on LAMOST Data Release 3 (DR3). This sample contains 151 spectroscopically confirmed quasars. Among them 80 are newly discovered with LAMOST. All these quasars are very bright, with  $i$  magnitudes peaking around 17.5 mag. All the new quasars were discovered serendipitously from objects that were originally targeted with LAMOST as stars having bluer colors, except for a few candidates targeted as variable, young stellar objects. This bright quasar sample at low Galactic latitudes will help fill the gap in the spatial distribution of known quasars near the Galactic disk that are used to construct an astrometric reference frame for the purpose of accurate proper motion measurements that can be applied to, for example, Gaia. They are also excellent tracers to probe the kinematics and chemistry of the interstellar medium in the Milky Way disk and halo via absorption line spectroscopy.

**Key words:** Galaxy: disk — quasars: emission lines — reference systems — proper motions — ISM: kinematics and dynamics

### 1 WHY SEARCH FOR QUASARS IN THE GALACTIC ANTI-CENTER AREA?

As of the recent 12th data release of the Quasar Catalog, the number of spectroscopically confirmed quasars had reached  $\sim 400\,000$  (Schneider et al. 2010; Pâris et al. 2012, 2014, 2017; Souchay et al. 2015 and references therein). Most of these quasars had been identified with the Sloan Digital Sky Survey (SDSS, York et al. 2000), and their spatial distribution is largely homogeneous in the approximately  $7500\text{ deg}^2$  area around the North Galactic Cap and about  $3100\text{ deg}^2$  surrounding the South Galactic Cap (see Schneider et al. 2010; Pâris et al. 2012,

2014, 2017). However, near the Galactic disk, especially for  $|b| \leq 30^\circ$ , the number of spectroscopically confirmed quasars remains very small. Only a few bright ones have been discovered hitherto, due to the lack of systematic spectroscopic surveys in those low Galactic latitudes, which is often covered with high dust extinction regions (see Souchay et al. 2015, Véron-Cetty & Véron 2010 and references therein).

Distant quasars are ideal objects to construct an inertial reference frame for accurate proper motion measurements by all sky astrometric survey missions such as Gaia (Perryman et al. 2001; Gaia Collaboration, Brown et al. 2016a; Gaia Collaboration, Prusti et al. 2016b;

Lindgren et al. 2016). Proper motion measurements are of vital importance for Galactic studies. Gaia uses a large number of all-sky distributed quasars, based on Souchay et al. (2008), to build an optical representation of the International Celestial Reference System (Andrei et al. 2009). However, the number of available quasars near the Galactic plane is quite low. Bright, distant quasars are also excellent tracers to study the foreground interstellar/intergalactic medium (ISM/IGM) along the line of sight and probe their properties such as distribution, chemical composition and kinematics. For instance, based on quasar absorption line spectroscopy, Savage et al. (2000) and Schneider et al. (1993) show that the halo gas of the Milky Way undergoes a wide range of ionization states, chemical compositions and kinematics.

The LAMOST Spectroscopic Survey of the Galactic Anti-Center (LSS-GAC) is a major component of the LAMOST Galactic surveys (Liu et al. 2014; Yuan et al. 2015), aiming to survey a significant volume of the Galactic thin/thick disks and halo for a contiguous sky area covering over  $3400 \text{ deg}^2$  centered on the GAC, within the range  $150^\circ \leq l \leq 210^\circ$  and  $|b| \leq 30^\circ$ . LSS-GAC targets are selected from the Xuyi Schmidt Telescope Photometric Survey of the Galactic Anti-Center (XSTPS-GAC; Liu et al. 2014; Zhang et al. 2014) photometric catalogs. The basic idea of LSS-GAC target selection is to uniformly and randomly select stars from color-magnitude diagrams using a Monte Carlo method. Stars with extremely blue or red colors are preferentially selected and targeted, see Yuan et al. (2015) for more details. As a consequence, one expects that some objects targeted by the LSS-GAC should contain a number of quasar candidates.

## 2 RESULTS

The current work is based on LAMOST Data Release 3 (DR3), which includes data collected from 2011 October 24 (the beginning of the Pilot Survey) to 2015 May 30. The quasar classifications and redshift measurements are produced by the LAMOST 1D pipeline. In the LAMOST 1D pipeline, the observed spectra are cross-correlated with star, galaxy and quasar template libraries. As a result, four spectral classifications, namely STAR, GALAXY, QUASAR and UNKNOWN, are produced, and radial velocities for stars or redshifts for galaxies and quasars are measured simultaneously (see Luo et al. 2015 for more details). However, all the 1D pipeline identifications and redshifts for quasars and galaxies are visually

inspected and adjusted if necessary before the final data release.

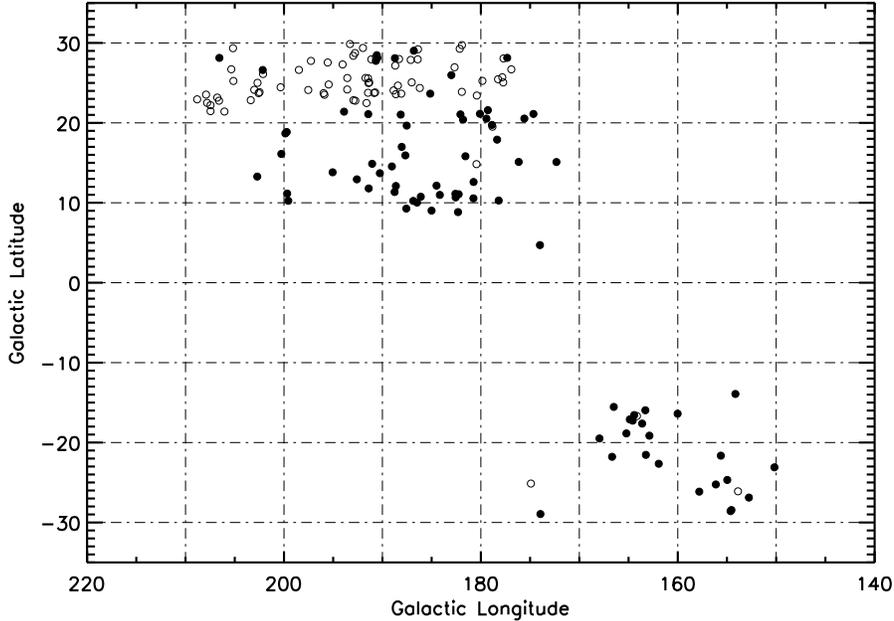
In this letter, we present 151 unique quasars from LAMOST DR3. Among them, 80 are reported here for the first time. The remaining 71 are listed in the Large Quasar Astrometric Catalog (LQAC) compiled recently by Souchay et al. (2015). Of the 151 quasars, 143 are identified by the LAMOST pipeline with classification as ‘QUASAR’ (Luo et al. 2015). In addition, we have visually examined approximately 80 000 spectra classified as ‘UNKNOWN’ by the LAMOST pipeline, either because of low signal noise ratios (SNRs) or for other reasons, for targets near the Galactic disk, in the range  $|b| \leq 15^\circ$ . This effort tries to identify as many quasars as possible, even from spectra with relatively low SNRs, for which the pipeline may fail to work properly. Quasars are easily identified given that their characteristic broad emission line spectra, and  $H\alpha$   $\lambda 6563$ ,  $[O \text{ III}]$   $\lambda\lambda 4959, 5007$ ,  $H\beta$   $\lambda 4861$ ,  $Mg \text{ II}$   $\lambda 2800$ ,  $C \text{ III}]$   $\lambda 1908$ ,  $C \text{ IV}$   $\lambda 1549$  and  $Ly\alpha$   $\lambda 1216$  lines are shifted into the LAMOST spectral wavelength range as the quasar’s redshift increases. Finally, we identified eight quasars from cases of ‘UNKNOWN’ spectra. For examples of LAMOST quasar spectra, please refer to our series of papers about background quasars in the vicinity of M31 and M33 (Huo et al. 2010, 2013, 2015). All of the spectra have been flux-calibrated, so we will not show them here.

Table 1 lists information on all the 151 quasars in the GAC area identified with LAMOST, including target name, J2000 coordinates of RA and Dec in decimal degree, redshift, the observed  $g$ ,  $r$ ,  $i$  magnitude if available, magnitude type (‘magtype’), object type from the LAMOST input catalog (‘objtype’), identified lines and notes. In the last column of Table 1, a flag ‘N’ indicates that the quasar is newly discovered by LAMOST, whereas ‘L’ indicates that it is listed in LQAC (Souchay et al. 2015). None of the 151 quasars were originally targeted by LAMOST as quasar candidates. Among them, 141, one and nine objects were originally targeted as stars with blue colors, variable sources selected from the WISE (Wright et al. 2010) photometric catalog and young stellar objects (‘yso’), respectively. The distribution of  $i$  band magnitudes from this sample of quasars peaks at 17.5 mag, with most of them having  $i$  magnitude between 16 and 18. The majority (141/151) of the quasars have a redshift lower than 2.2. Only 11 quasars have higher redshifts, with the highest redshift value being 3.43.

**Table 1** Catalog of Quasars in the GAC Area from LAMOST DR3

Object	R.A.	Dec. (J2000)	Redshift	<i>g</i>	<i>r</i>	<i>i</i>	magtype	objtype	Lines	Note*
J025226.35+331721.0	43.109796	33.289167	0.53	17.15	17.10	16.96	<i>gri</i>	Star	Mg II, H $\gamma$ , H $\beta$ , [O III]	N
J025311.52+285016.0	43.298027	28.837802	0.56	17.86	17.74	17.57	<i>gri</i>	Star	Mg II, H $\beta$	N
J025539.40+263218.3	43.914171	26.538418	0.53	17.78	18.29	17.75	<i>gri</i>	Star	Mg II, [O III], H $\gamma$ , H $\beta$ , [O III]	N
J025540.49+264119.3	43.918725	26.688717	0.29	17.55	17.54	17.27	<i>gri</i>	Star	H $\gamma$ , H $\beta$ , [O III], H $\alpha$	N
J025855.16+290001.3	44.729862	29.000370	2.48	–	–	17.30	<i>i</i>	yso	Ly $\alpha$ , N v, Si IV, C IV, C III]	L
J030613.11+294029.0	46.554666	29.674743	0.89	18.23	17.70	17.88	<i>gri</i>	Star	Mg II, H $\gamma$	N
J030850.72+283738.2	47.211350	28.627296	2.09	18.15	17.79	17.65	<i>gri</i>	Star	Ly $\alpha$ , N v, Si IV, C IV, C III], Mg II	N
J031212.67+270143.7	48.052832	27.028832	3.43	18.49	17.93	17.71	<i>gri</i>	Star	O VI, Ly $\alpha$ , N v, Si IV, C IV, C III]	N
J031624.33+315225.0	49.101390	31.873619	0.17	18.24	17.56	16.69	<i>gri</i>	Star	H $\beta$ , O III, H $\alpha$	N
J033243.77+385859.5	53.182404	38.983215	1.84	17.97	17.71	17.39	<i>gri</i>	Star	C IV, C III], Mg II	N

Notes: \*N represents the quasars that are newly discovered by LAMOST, whereas ‘L’ represents the ones that are listed in LQAC (Souhay et al. 2015). Only a portion of the table is shown here for illustration. The whole table which contains information on 151 quasars is available in the online electronic version.



**Fig. 1** Spatial distribution of all background quasars in the GAC area identified from LAMOST DR3. Filled circles represent newly discovered quasars and open circles represent those already listed in LQAC (Souhay et al. 2015).

Figure 1 plots the spatial distribution of this sample of quasars found in the GAC area, in Galactic coordinates, including the 80 quasars newly identified with LAMOST and the 71 previously known ones. The newly discovered quasars are distributed closer to the Galactic plane than previously known ones. This sample of quasars will help fill the gap in the spatial distribution of quasars near the Galactic disk that are used to build an astrometric reference frame for proper motion

measurements. They are also valuable sources to probe kinematics and chemistry of the ISM associated with the Milky Way disk and halo.

### 3 SUMMARY

We present 151 quasars discovered in the GAC area of  $150^\circ \leq l \leq 210^\circ$  and  $|b| \leq 30^\circ$ , from LAMOST DR3. Among them, 80 are newly discovered with LAMOST. These bright quasars will help fill the gap in the spa-

tial distribution of known quasars near the Galactic disk that are used to construct an astrometric reference frame for the purpose of accurate proper motion measurements, and will also serve as tracers to probe the properties of the ISM associated with the Milky Way disk and halo. We will present more quasars near the Galactic disk in the future with more data collected by LAMOST.

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