Identification of FeLoBAL Quasars in SDSS DR7Q Using Convolutional Neural Networks (Postprint)

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Date: 2025-06-16T14:58:43+00:00

Abstract

Iron low-ionization broad absorption line quasars (Fe Low-ionization Board Absorption Line Quasar, FeLoBALQ) represent one of the rarest subclasses of quasars. The radiation from these objects violently expels surrounding material, forming powerful high-velocity outflows in which low-ionization species, notably iron, absorb the quasar radiation and produce characteristic low-ionization iron broad absorption line spectra. The energy carried by FeLoBALQ outflows is sufficient to explain the \$ M - ** \$ relationship between supermassive black hole mass \$ M \$ and host galaxy bulge velocity dispersion \$* * \$, while some studies indicate that FeLoBALQs may be associated with starburst galaxies or major mergers. However, the limited number of FeLoBALQs discovered to date has hindered statistical verification of these theories. This research program conducts a large-scale search within existing large quasar samples to identify FeLoBALQs among previously discovered quasars, thereby providing a foundational sample for further investigation. Employing the convolutional neural network (Convolutional Neural Network, CNN) method from deep learning and utilizing previously discovered FeLoBALQ spectra as training samples, we have identified 160 new FeLoBALQ spectra from a total of 50,931 quasar spectra in the SDSS (Sloan Digital Sky Survey) DR7Q (Data Release 7 Quasar catalog) within the redshift range \$ 0.8 < z < 2.125 \$. The study reveals that FeLoBALQs are redder than typical quasars, with previously discovered FeLoBALQs being slightly redder than the newly identified ones; these differences are more pronounced at the blue end and nearly vanish in the mid-infrared regime. Combining previously discovered FeLoBALQs with our new identifications, we estimate that the fraction of FeLoBALQs among the total quasar population within this redshift range of the sample is approximately \$ 0.43% \$, a value slightly higher than previous estimates but potentially still underestimated. Future work aims to extend this method to larger samples such as SDSS DR16Q

(Data Release 16 Quasar catalog) to discover additional FeLoBALQs and to employ large samples to investigate the relationship between FeLoBALQs and host galaxy star formation, major galaxy mergers, and the co-evolution of galaxies and their central supermassive black holes.

Full Text

Preamble

Vol. 66 No. 3
May, 2025

Acta Astronomica Sinica

Identifying FeLoBAL Quasars in SDSS DR7Q Using the Convolutional Neural Network Method

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Abstract

Iron low-ionization broad absorption line quasars (FeLoBALQs) represent one of the rarest subclasses of quasars. The radiation from these objects violently expels surrounding material, forming powerful high-velocity outflows. Low-ionization species, particularly iron, absorb the quasar radiation and produce characteristic broad absorption features from low-ionization iron. The outflows in FeLoBALQs carry sufficient energy to explain the M–σ relation between supermassive black hole mass and host galaxy bulge velocity dispersion, and studies suggest FeLoBALQs may be associated with starburst galaxies or major galaxy mergers. However, the limited number of FeLoBALQs discovered to date has hindered statistical verification of these theories. This research aims to conduct a large-scale search for FeLoBALQs within existing quasar samples to provide a foundation for further study. Using the convolutional neural network (CNN) method from deep learning, we identified 160 FeLoBALQ spectra from a total of 50,931 quasar spectra in the SDSS (Sloan Digital Sky Survey) DR7Q (Data Release 7 Quasar catalog) within the redshift range M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:8<z<2:1250:43%. We find that FeLoBALQs are redder in color than typical quasars, with previously discovered FeLoBALQs appearing slightly redder than the newly identified ones.

These differences are more pronounced at bluer wavelengths and nearly disappear in the mid-infrared. Combining our new discoveries with previously known FeLoBALQs, we estimate that FeLoBALQs constitute approximately M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:8<z<2:1250:43% of all quasars in this redshift range, a fraction slightly higher than previous estimates but likely still underestimated. Future work will extend this method to larger samples such as SDSS DR16Q (Data Release 16 Quasar catalog) to discover more FeLoBALQs and enable large-sample studies of their relationship with host galaxy star formation, major mergers, and the co-evolution of galaxies and central supermassive black holes.

Keywords: galaxies: active, quasars: absorption lines, methods: deep learning, catalogs

PACS codes: P158; **Document code:** A

1 Introduction

Among broad absorption line (BAL) quasars, iron low-ionization broad absorption line quasars (FeLoBALQs) represent an extremely special subclass. The primary observational characteristic of these quasars is the presence of low-ionization iron absorption lines, dominated by Fe II with some objects showing Fe III, occasionally accompanied by strong absorption features from He I, Si II, and Ni II. The ionization potential for iron is lower than that for C IV (which characterizes high-ionization BALs or HiBALs) and Mg II (which characterizes low-ionization BALs or LoBALs). This indicates that the outflowing gas in FeLoBALQs originates at greater distances from the central region than in typical LoBAL quasars, suggesting more extreme outflow phenomena. Research indicates that establishing the famous M–σ relation in the co-evolution of galaxies and central black holes requires approximately 5% of the quasar's bolometric luminosity [?, ?], while Moe et al. [?] demonstrated that the kinematic luminosity of FeLoBALQ outflows reaches 1% of the bolometric luminosity, making it a significant component of the energy driving co-evolution. Faucher-Giguère et al. [?] showed that for the most luminous FeLoBALQs, this fraction can reach M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)2%(cid:0)5%18%(cid:12), potentially sufficient to entirely drive co-evolution. These studies suggest that quasars in the FeLoBALQ state may play a crucial role in establishing the relationship between central black holes and their host galaxies.

Since their discovery, the physical mechanisms and origins of FeLoBALQs have remained pressing questions. However, the rarity of these objects has limited systematic studies and prevented statistically robust conclusions. First, no consensus has been reached regarding the mechanism of FeLoBAL formation. Yuan et al. [?] and Runnoe et al. [?] found that BAL quasars exhibit weaker [O III] emission lines and stronger Fe II emission, implying higher accretion rates than non-BAL quasars. In contrast, Schulze et al. [?] studied LoBAL quasars and FeLoBALQs, and Rankine et al. [?] studied BAL quasars, concluding that the accretion rates of BALs and their subclasses (including LoBALs and FeLoB-

ALs) are similar to those of non-BAL quasars, contradicting earlier studies. Additionally, no unified model for FeLoBALQ formation has emerged. Farrah et al. [?] proposed in 2010 that FeLoBALQs may exist in environments satisfying three conditions: (1) the galaxy is in the late stage of a starburst driven by a major merger, (2) a high-luminosity quasar is in the late stage of accreting surrounding dust, and (3) we are observing from a specific viewing angle. This scenario has received support from several studies: Farrah et al. [?] discovered four quasars at the centers of ultraluminous infrared galaxies (ULIRGs) in 2005, one of which was a FeLoBALQ. The extreme infrared luminosity of ULIRGs indicates abundant warm gas and dust and extremely high star formation rates. Farrah et al. [?] conducted infrared observations of nine FeLoBALQs in 2007, finding their infrared luminosities consistent with ULIRGs and optical features indicating star formation rates of several hundred solar masses per year. This study suggested an inevitable connection between FeLoBALQs and the extreme star formation rates of their host galaxies, likely indicating co-evolution between the quasar and host. Lawther et al. [?] performed high-resolution observations of FeLoBALQs, confirming evidence of past major mergers in their environments. However, some studies have challenged this scenario: Violino et al. [?] conducted submillimeter observations of 17 FeLoBALQs and found no correlation between FeLoBALQs and star formation in host galaxies. Villforth et al. [?] performed high-resolution observations but found no evidence of major mergers in the environments of FeLoBALQs.

The primary reason for these inconsistent conclusions is the small number of FeLoBALQs discovered to date, making studies of limited samples susceptible to significant statistical uncertainties. Research on FeLoBALQs requires larger samples to yield statistically convincing results. The series of studies by Leighly and Choi et al. [?] on the spectral properties of FeLoBALQs, using a sample of 50 objects, represents the largest and most systematic recent work on FeLoBALQs, yielding consistent conclusions: using absorption features to study outflows, they found a positive correlation between outflow strength and velocity, with FeLoBALQ outflow strength sufficient to provide quasar feedback to host galaxies [?]. Their study of emission line strengths revealed that Hβ lines in FeLoBALQs are generally broader, suggesting either high inclination angles or a lack of low-velocity emitting gas. After calculating accretion rates from emission strengths, they classified FeLoBALQs into low-luminosity, low-accretion-rate and high-luminosity, high-accretion-rate types [?]. Using models to study the locations of broad absorption features in both types, they found that for high-luminosity FeLoBALQs, the distance of broad absorption formation from the quasar center correlates negatively with accretion rate, while the opposite holds for low-luminosity types [?]. Comparing spectral energy distributions (SEDs) of FeLoBALQs with those of typical quasars, they found significant differences in emission lines and other parameters between FeLoBALQs, LoBAL quasars, and normal quasars, suggesting FeLoBALQs may be a particularly special class of quasars [?].

These series of studies, supported by a moderately sized FeLoBALQ sample, have yielded results with some degree of universality. However, to verify these theories and support more systematic investigations of FeLoBALQ properties, larger samples are needed. The purpose of this study is to conduct a large-scale search and identification of FeLoBALQs, effectively expanding the FeLoBALQ sample set to provide crucial data support for systematic studies of FeLoBALQs and necessary statistical foundations for frontier research on galaxy-AGN co-evolution, quasar structure and physical properties, quasar classification, and astronomical statistics.

This paper employs the convolutional neural network (CNN) method from machine learning [?]. By using previously discovered FeLoBALQ spectra and normal quasar spectra as training sets, the program learns to identify FeLoBALQ spectra, which is then applied to the SDSS (Sloan Digital Sky Survey) DR7Q (Data Release 7 Quasar catalog) [?] to search for previously unidentified FeLoBALQ spectra, providing a solid sample foundation for future systematic studies. Since FeLoBALQs represent a small fraction of the population and their absorption features can be confused with other BALs, we restrict the redshift range of both training and target samples to M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:8<z<2:1250:43% to ensure that the absorption features of interest in the rest-frame wavelength range of 2000–3200 Å fall entirely within the effective spectral coverage.

Section 2 introduces the training and target samples, the CNN methodology, and important details of our research process. Section 3 presents the FeLoBALQ identification results and potential improvements. Section 4 summarizes the entire paper, clarifies its scientific significance, and outlines future research directions.

2.1 Redshift Selection and Target Sample

During preliminary testing using unprocessed spectra for CNN training and identification, we found that many spectra classified as FeLoBALQ showed only C IV or Mg II absorption components without clear Fe II absorption. Initial analysis revealed that different types of BALs have similar absorption profiles—all resembling Gaussian functions except for FeLoBALs, which produce continuous absorption troughs. Combined with redshift shifting absorption lines to arbitrary positions in the spectrum, the program struggled to distinguish whether absorption lines originated from Fe II rather than other elements.

Therefore, we truncated the spectra for both training and target samples, using only the rest-frame wavelength range of 2000–3200 Å that likely contains strong Fe absorption features. We retained Mg II as a reference while minimizing interference from C IV, Al III, and other contaminating features. The primary flux contributions in this band come from the quasar continuum, iron continuum emission, and the Mg II broad emission line, upon which iron absorption features are prominently displayed with minimal interference from other absorption components except for the Mg II broad absorption line. Based on the SDSS BOSS (Baryon Oscillation Spectroscopic Survey)/eBOSS (extended BOSS) spectral wavelength range of 3600–10000 Å, we selected the redshift range M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:8<z<2:1250:43% to ensure the 2000–3200 Å rest-frame band is fully covered. For quasars in our SDSS DR7Q sample with redshifts around 2, the red end may not reach 3200 Å in the rest frame, but this does not significantly affect FeLoBALQ identification, and we include them to facilitate future comparative studies with SDSS DR16Q (Data Release 16 Quasar catalog) [**?**].

We selected the SDSS DR7Q catalog, applying redshift constraints to obtain 50,931 spectra as our target sample. This sample represents an important milestone of SDSS, with well-established scientific validity and a moderate size that facilitates methodological iteration and research development. It also allows convenient extension to the SDSS DR16Q sample.

Since many quasar spectra have low signal-to-noise ratios, using SDSS spectral intersection masks (and mask) or union masks (or mask) to flag bad pixels would eliminate substantial useful information. Therefore, we employed standard deviation clipping (σ-clipping) to mask interference such as sky lines. We then transformed the spectra to the rest frame, extracted the 2000–3200 Å wavelength range, and resampled to one data point per Ångström (to satisfy CNN requirements for uniform data length). We subtracted the mean flux of this band from each data point to reduce the impact of the continuum and highlight absorption and emission features. Finally, we applied smoothing to the spectra before CNN input to reduce noise interference and emphasize macroscopic features such as broad absorption lines.

2.2 Training Sample Selection

To train the CNN program, we compiled FeLoBALQs identified in previous studies [**?**], totaling 220 FeLoBALQ sources. We used their SDSS spectra as training samples. Among these 220 sources, 186 were located in SDSS. Counting multiple observations of the same source, we obtained 354 FeLoBALQ spectra. To ensure training quality, we retained only high-quality spectra with prominent iron absorption features, leaving 319 FeLoBALQ spectra. After applying the redshift restriction, the sample contained 167 spectra. During trial runs to validate CNN performance, we identified 33 additional FeLoBALQ spectra, which were added to expand the training sample. The final training sample included 200 FeLoBALQ spectra. We also randomly selected 379 non-FeLoBAL quasar spectra of varying quality to help the program learn to distinguish unique FeLoBALQ features. We used these 579 spectra as our total CNN training sample, randomly dividing them in a ratio of approximately M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)2%(cid:0)5%18%(cid:12). The training set contained 153 FeLoBALQ and 282 non-FeLoBALQ spectra for CNN training, while the test set contained 47 FeLoBALQ and 97 non-FeLoBALQ spectra to determine when the CNN achieved stable identification accuracy (using the model at that iteration stage for target sample classification). We applied the same data processing pipeline to training sample spectra as used for the target sample.

2.3 CNN Structure and Training

We chose the CNN method for spectral identification primarily because CNNs excel at image recognition, and spectra can be treated as one-dimensional images. We constructed the CNN with five alternating convolutional and pooling layers to extract spectral features. The convolutional layers had kernel sizes of 3, 3, 5, 5, and 5, respectively, while all pooling layers used kernel size 2. The model then fed into two fully connected layers with 360 and 50 hidden units for FeLoBALQ classification. The neural network employed Rectified Linear Units (ReLU) [**?**, **?**] as activation functions to improve noise robustness and avoid gradient vanishing during training. The neural network structure is illustrated in Figure 1 [Figure 1: see original paper].

Figure 1 Convolutional neural network structure used in this research.

We input the training sample into the CNN network, using the training set to train the model and the test set to validate results and provide feedback. After 20 iterations, the classification accuracy on the test set stabilized at M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)2%(cid:0)5%18%(cid:12). Therefore, we selected the model after 20 iterations to classify the target sample. The confusion matrix at this stage is shown in Figure 2 [Figure 2: see original paper].

Figure 2 Confusion matrix for the test set when the CNN stabilized at the 20th iteration.

3 Results

We input the target sample into the trained CNN model, which identified approximately 1,000 FeLoBALQ candidate spectra. After manual inspection, we excluded spectra with weak iron absorption features that were difficult to confirm as FeLoBALQs and removed spectra already present in the training sample, yielding 160 newly discovered FeLoBALQ spectra (including 33 identified during the trial phase). Example spectra are shown in Figure 3 [Figure 3: see original paper]. Appendix 1 provides detailed information for the newly discovered FeLoBALQs, including SDSS name, right ascension (RA) and declination (Dec), SDSS spectral identification (plate number, Modified Julian Date MJD, and fiber number), redshift (z), SDSS u, g, r, i, z band magnitudes, and WISE (Wide-field Infrared Survey Explorer) W1 and W2 band magnitudes.

Figure 3 Example spectra of four newly identified FeLoBALQs in this research. Each panel shows the locally observed full spectrum in the inset (top left), with local observed wavelength on the x-axis and local observed flux on the y-axis. Red dashed lines mark 2000 Å and 3200 Å in the rest frame, representing our wavelength range of interest. The main plot shows the spectral detail in the rest-frame wavelength range used by our CNN, transformed using each FeLoBALQ's redshift value. Green and cyan dashed lines indicate absorption lines from Hall et al. [?] Table 1 (cyan marks Mg II absorption, a hallmark of BALs), blueshifted from the tabulated wavelengths. The blueshift velocity (outflow velocity) is given in each title. The tabulated absorption lines cannot fully match the observed features, and varying absorption strengths and widths among different FeLoBALQ spectra produce different absorption profiles, making conventional identification methods difficult and necessitating machine learning approaches.

We constructed color-color diagrams comparing the target sample (SDSS DR7Q quasars) with the training sample (previously known FeLoBALQs only, excluding trial-run identifications) and our 160 newly discovered FeLoBALQ candidates, shown in Figure 4 [Figure 4: see original paper]. Since all three samples lie primarily off the Galactic plane with minimal Milky Way extinction, and share similar redshift ranges, we calculated colors directly from observed magnitudes for statistical analysis. Relative to the target sample, FeLoBALQs are generally redder, with the difference more pronounced at bluer wavelengths and nearly vanishing in the mid-infrared W1–W2 color. Physically, the bluer portion of quasar spectra is increasingly dominated by continuum emission, and FeLoBALQ outflows produce stronger extinction of this continuum, resulting in redder colors. Figure 4 supports this interpretation. The newly discovered FeLoBALQs show similar color distributions to previously known ones, though the previously known objects are slightly redder overall. This can be explained by the following: stronger absorption in FeLoBALQ outflows produces redder colors; objects with stronger absorption exhibit more prominent absorption complexes and troughs in their spectra, making them easier to discover in earlier studies and causing them to appear systematically redder. Conversely, FeLoBALQs with weaker absorption are generally discovered later, comprising a larger fraction of our new candidates.

Figure 4 Color-color diagram for FeLoBALQs and SDSS DR7Q quasars for statistical analysis, using four colors calculated from SDSS g, r, i, z band magnitudes and WISE W1, W2 band magnitudes. Red dots represent FeLoBALQs newly identified in this research, green dots represent previously identified FeLoBALQs, and black dots represent DR7Q quasars. FeLoBALQs are redder than other quasars, with previously identified ones slightly redder than newly identified ones. This effect is more obvious at the bluer end than the redder end, and color differences nearly disappear in mid-infrared W1–W2.

The training sample contains 61 spectra from SDSS DR7Q. Currently, 221 FeLoBALQ spectra have been discovered within the SDSS DR7Q range, representing M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:43% of the total 50,931 spectra—slightly higher than the 0.33% fraction reported by Trump et al. [?] in 2006. We believe the true fraction of FeLoBALQs among all quasars should be larger than this value. First, FeLoBALQs are redder than other quasars, and outflow absorption makes them fainter in the optical and near-infrared bands as observed from Earth, increasing confusion with brown dwarfs and causing them to be missed during optical target selection. Second, the dramatic absorption features in FeLoBALQ spectra make classification and redshift determination difficult (for example, some FeLoBALQs in our training sample were classified as galaxies by SDSS), causing them to escape target sample selection.

4 Summary and Outlook

In this paper, we used previously identified FeLoBALQ spectra as training samples to establish a CNN model for FeLoBALQ identification and classification. Based on the absorption characteristics of FeLoBALQs, we determined a redshift range of M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:8<z<2:1250:43% for our target quasars. We classified all 50,931 quasar spectra from SDSS DR7Q in this range, discovering 160 new FeLoBALQ candidates and estimating that FeLoBALQs constitute M(cid:27)(cid:3)M(cid:0)(cid:27)(cid:3)0:8<z<2:1250:43% of quasars in this redshift interval. We briefly analyzed why FeLoBALQs appear redder than other quasars and discussed potential statistical biases in our study.

Future work will include continuous improvement of the program and CNN architecture, refinement of training samples, and extension of FeLoBALQ identification to the SDSS DR16Q sample (330,386 spectra, excluding those from SDSS DR7Q) in the same redshift range. We expect to discover approximately 1,400 FeLoBALQ spectra in this sample, with about 1,100 being newly identified, thereby substantially expanding the existing FeLoBALQ catalog and providing data support for related research.

Additionally, we plan to conduct high-resolution imaging, spectroscopic, and multi-band photometric observations of FeLoBALQ candidates in our sample. High-resolution imaging will search for signs of major mergers in host galaxies, addressing whether FeLoBALQs are primarily triggered by major mergers. High-resolution spectroscopy and multi-band photometry will provide more precise confirmations and determine physical parameters including black hole mass, bolometric luminosity, outflow velocity and strength, and host galaxy star formation rates. Analysis of these collected physical properties will help answer whether FeLoBALQs are associated with ULIRGs and whether they represent an evolutionary stage from ULIRGs to quasars. Furthermore, by comparing physical properties of FeLoBALQs at different redshifts, we will investigate whether the FeLoBALQ occurrence rate correlates with redshift and cosmic age, which is crucial for understanding galaxy-supermassive black hole co-evolution.

Acknowledgments

This research utilized high-quality data from the SDSS and WISE projects, the ADS and arXiv databases and CDS database for literature searches and sample collection, and the TOPCAT and ASERA software for data table processing and spectral visualization. We also used the numpy, scipy, pytorch, astropy, and specutils packages. We express our gratitude to these projects, databases, and software packages. We thank the referee for valuable comments and Li Ruancun for helpful suggestions.

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Appendix 1 Table of Newly Discovered FeLoBALQ Sources

Table 1 FeLoBALQs newly identified in this study

SDSS Name	RA	Dec	Plate	MJD	Fiber	z	u	g	r	i	z	W1	W2
J1050-0105	163.8653	-1.0988	...	...	...	...	...	...	...	...	...	...	...
J1055+0020	163.8653	0.3387	...	...	...	...	...	...	...	...	...	...	...
J1240+0017	190.1199	0.2953	...	...	...	...	...	...	...	...	...	...	...

SDSS Name	RA	Dec	Plate	MJD	Fiber	z	u	g	r	i	z	W1	W2
J1310+0104	197.5286	1.0735	...	...	...	...	...	...	...	...	...	...	...
J1316-0036	199.0434	-0.6100	...	...	...	...	...	...	...	...	...	...	...
J1339+0009	204.9391	0.1589	...	...	...	...	...	...	...	...	...	...	...
J1447-0034	221.9385	-0.5677	...	...	...	...	...	...	...	...	...	...	...
J1209+0045	182.3844	0.7544	...	...	...	...	...	...	...	...	...	...	...
J2336-0107	354.0709	-1.1260	...	...	...	...	...	...	...	...	...	...	...
J0338+0056	54.5415	0.9389	...	...	...	...	...	...	...	...	...	...	...
J0156+1352	29.1237	13.8708	...	...	...	...	...	...	...	...	...	...	...
J0207+1429	31.8638	14.4980	...	...	...	...	...	...	...	...	...	...	...
J0805+4535	121.3853	45.5955	...	...	...	...	...	...	...	...	...	...	...
J0242-0722	40.6830	-7.3682	...	...	...	...	...	...	...	...	...	...	...
J0918+5833	139.7270	58.5587	...	...	...	...	...	...	...	...	...	...	...
J0948+6214	147.1910	62.2407	...	...	...	...	...	...	...	...	...	...	...
J1239+0235	189.8984	2.5939	...	...	...	...	...	...	...	...	...	...	...
J1010+5723	152.5962	57.3899	...	...	...	...	...	...	...	...	...	...	...
J1020+0330	155.0584	3.5086	...	...	...	...	...	...	...	...	...	...	...
J1056+0549	164.0344	5.8308	...	...	...	...	...	...	...	...	...	...	...
J1457+0426	224.3734	4.4419	...	...	...	...	...	...	...	...	...	...	...
J1420+6047	215.0429	60.7950	...	...	...	...	...	...	...	...	...	...	...
J1628+4755	247.0228	47.9252	...	...	...	...	...	...	...	...	...	...	...
J1649+4014	252.4245	40.2408	...	...	...	...	...	...	...	...	...	...	...
J2347-1037	356.7977	-10.6285	...	...	...	...	...	...	...	...	...	...	...
J2357-0903	359.2702	-9.0540	...	...	...	...	...	...	...	...	...	...	...
J0102-0853	15.5064	-8.8957	...	...	...	...	...	...	...	...	...	...	...
J0121-0929	20.3620	-9.4847	...	...	...	...	...	...	...	...	...	...	...
J2137+1041	324.3145	10.6864	...	...	...	...	...	...	...	...	...	...	...
J2204+1327	331.0915	13.4561	...	...	...	...	...	...	...	...	...	...	...
J0026+1355	6.6667	13.9258	...	...	...	...	...	...	...	...	...	...	...
J1120+6204	170.0069	62.0832	...	...	...	...	...	...	...	...	...	...	...
J1202+6317	180.5080	63.2998	...	...	...	...	...	...	...	...	...	...	...
J1448+5639	222.1614	56.6553	...	...	...	...	...	...	...	...	...	...	...
J1534+5147	233.6083	51.7924	...	...	...	...	...	...	...	...	...	...	...
J1530+5115	232.6190	51.2540	...	...	...	...	...	...	...	...	...	...	...
J1233+0608	188.3692	6.1357	...	...	...	...	...	...	...	...	...	...	...
J1319+0550	199.9602	5.8381	...	...	...	...	...	...	...	...	...	...	...
J1337+0527	204.4713	5.4592	...	...	...	...	...	...	...	...	...	...	...
J1344-0158	206.2090	-1.9786	...	...	...	...	...	...	...	...	...	...	...
J1348-0153	207.1283	-1.8994	...	...	...	...	...	...	...	...	...	...	...
J1527-0210	231.8533	-2.1820	...	...	...	...	...	...	...	...	...	...	...
J0743+2209	115.8371	22.1625	...	...	...	...	...	...	...	...	...	...	...
J1010+4518	152.7249	45.3047	...	...	...	...	...	...	...	...	...	...	...
J1011+5712	152.8634	57.2049	...	...	...	...	...	...	...	...	...	...	...
J1006+0513	151.5236	5.2208	...	...	...	...	...	...	...	...	...	...	...
J0801+3153	120.4164	31.8916	...	...	...	...	...	...	...	...	...	...	...

SDSS Name	RA	Dec	Plate	MJD	Fiber	z	u	g	r	i	z	W1	W2
J2140-0653	325.0573	-6.8969	...	...	...	...	...	...	...	...	...	...	...
J0834+0613	128.6812	6.2214	...	...	...	...	...	...	...	...	...	...	...
J1145+1100	176.4844	11.0051	...	...	...	...	...	...	...	...	...	...	...
J1041+0925	160.4975	9.4236	...	...	...	...	...	...	...	...	...	...	...
J0811+2452	122.7508	24.8753	...	...	...	...	...	...	...	...	...	...	...
J0912+3515	138.1266	35.2607	...	...	...	...	...	...	...	...	...	...	...
J1302+4859	195.7349	48.9979	...	...	...	...	...	...	...	...	...	...	...
J1333+4916	203.4295	49.2731	...	...	...	...	...	...	...	...	...	...	...
J0912+0915	138.2305	9.2542	...	...	...	...	...	...	...	...	...	...	...
J1239+5755	189.8757	57.9288	...	...	...	...	...	...	...	...	...	...	...
J1359+5532	209.7715	55.5383	...	...	...	...	...	...	...	...	...	...	...
J1054+4428	163.5484	44.4790	...	...	...	...	...	...	...	...	...	...	...
J1440+3710	220.0093	37.1829	...	...	...	...	...	...	...	...	...	...	...
J1155+4659	178.7997	46.9844	...	...	...	...	...	...	...	...	...	...	...
J0003+0010	0.8588	0.1750	...	...	...	...	...	...	...	...	...	...	...
J1646+1943	251.7298	19.7169	...	...	...	...	...	...	...	...	...	...	...
J1612+2516	243.1798	25.2691	...	...	...	...	...	...	...	...	...	...	...
J1617+2509	244.4265	25.1595	...	...	...	...	...	...	...	...	...	...	...
J1539+3205	234.9968	32.0863	...	...	...	...	...	...	...	...	...	...	...
J1547+3230	236.9257	32.5133	...	...	...	...	...	...	...	...	...	...	...
J0823+2446	125.9606	24.7814	...	...	...	...	...	...	...	...	...	...	...
J1539+0737	234.9619	7.6222	...	...	...	...	...	...	...	...	...	...	...
J1610+0713	242.5280	7.2208	...	...	...	...	...	...	...	...	...	...	...
J0743+4357	115.9192	43.9516	...	...	...	...	...	...	...	...	...	...	...
J0949+1237	147.4285	12.6292	...	...	...	...	...	...	...	...	...	...	...
J1022+1301	155.7053	13.0236	...	...	...	...	...	...	...	...	...	...	...
J1043+1327	160.8329	13.4635	...	...	...	...	...	...	...	...	...	...	...
J1102+1438	165.5593	14.6479	...	...	...	...	...	...	...	...	...	...	...
J0832+0758	128.1919	7.9661	...	...	...	...	...	...	...	...	...	...	...
J0825+0652	126.2604	6.8681	...	...	...	...	...	...	...	...	...	...	...
J1222+1423	185.6569	14.3975	...	...	...	...	...	...	...	...	...	...	...
J1336+0830	204.1352	8.5086	...	...	...	...	...	...	...	...	...	...	...
J1335+1018	203.8563	10.3108	...	...	...	...	...	...	...	...	...	...	...
J1432+0547	218.0984	5.7897	...	...	...	...	...	...	...	...	...	...	...
J1507+2906	226.7806	29.1020	...	...	...	...	...	...	...	...	...	...	...
J1543+2640	235.7635	26.6812	...	...	...	...	...	...	...	...	...	...	...
J1553+2358	238.4001	23.9767	...	...	...	...	...	...	...	...	...	...	...
J1548+2432	237.1518	24.5477	...	...	...	...	...	...	...	...	...	...	...
J1551+2544	237.7571	25.7400	...	...	...	...	...	...	...	...	...	...	...
J0800+1943	120.0628	19.7332	...	...	...	...	...	...	...	...	...	...	...
J1022+3459	155.5697	34.9916	...	...	...	...	...	...	...	...	...	...	...
J1029+3701	157.4323	37.0242	...	...	...	...	...	...	...	...	...	...	...
J1326+2839	201.5101	28.6660	...	...	...	...	...	...	...	...	...	...	...
J1232+4106	188.0754	41.1105	...	...	...	...	...	...	...	...	...	...	...

SDSS Name	RA	Dec	Plate	MJD	Fiber	z	u	g	r	i	z	W1	W2
J1234+3839	188.6472	38.6542	...	...	...	...	...	...	...	...	...	...	...
J1147+3734	176.9181	37.5775	...	...	...	...	...	...	...	...	...	...	...
J1306+3258	196.6789	32.9676	...	...	...	...	...	...	...	...	...	...	...
J1245+3412	191.3790	34.2026	...	...	...	...	...	...	...	...	...	...	...
J0206+2227	31.6848	22.4567	...	...	...	...	...	...	...	...	...	...	...
J0133+2333	23.4082	23.5583	...	...	...	...	...	...	...	...	...	...	...
J1409+2729	212.2780	27.4947	...	...	...	...	...	...	...	...	...	...	...
J1635+1415	248.8957	14.2657	...	...	...	...	...	...	...	...	...	...	...
J1215+2934	183.9463	29.5694	...	...	...	...	...	...	...	...	...	...	...
J1230+2759	187.7432	27.9901	...	...	...	...	...	...	...	...	...	...	...
J1248+2846	192.1400	28.7691	...	...	...	...	...	...	...	...	...	...	...
J0813+1345	123.3874	13.7543	...	...	...	...	...	...	...	...	...	...	...
J0033+0632	8.4923	6.5403	...	...	...	...	...	...	...	...	...	...	...
J1017+2303	154.3460	23.0562	...	...	...	...	...	...	...	...	...	...	...
J1000+2006	150.2145	20.1102	...	...	...	...	...	...	...	...	...	...	...
J1022+2158	155.6002	21.9758	...	...	...	...	...	...	...	...	...	...	...
J0249+3320	42.3408	33.3347	...	...	...	...	...	...	...	...	...	...	...
J1042-0008	160.6780	-0.1392	...	...	...	...	...	...	...	...	...	...	...
J1045+2210	161.2578	22.1779	...	...	...	...	...	...	...	...	...	...	...
J1050+2004	162.6271	20.0728	...	...	...	...	...	...	...	...	...	...	...
J1114+2222	168.5054	22.3699	...	...	...	...	...	...	...	...	...	...	...
J1133+2231	173.2800	22.5186	...	...	...	...	...	...	...	...	...	...	...
J1632+0942	248.0821	9.7069	...	...	...	...	...	...	...	...	...	...	...
J0849+1125	132.3015	11.4273	...	...	...	...	...	...	...	...	...	...	...
J1209+1651	182.2910	16.8590	...	...	...	...	...	...	...	...	...	...	...
J1214+1749	183.6254	17.8187	...	...	...	...	...	...	...	...	...	...	...
J1227+1750	186.9019	17.8497	...	...	...	...	...	...	...	...	...	...	...
J1259+2057	194.7994	20.9606	...	...	...	...	...	...	...	...	...	...	...
J1305+1932	196.4866	19.5444	...	...	...	...	...	...	...	...	...	...	...
J1334+2004	203.5659	20.0771	...	...	...	...	...	...	...	...	...	...	...
J1247+2323	191.9088	23.3933	...	...	...	...	...	...	...	...	...	...	...
J1316+2507	199.0522	25.1236	...	...	...	...	...	...	...	...	...	...	...
J1338+2246	204.6095	22.7751	...	...	...	...	...	...	...	...	...	...	...
J1439+1535	219.9281	15.5876	...	...	...	...	...	...	...	...	...	...	...
J1524+1153	231.0966	11.8867	...	...	...	...	...	...	...	...	...	...	...
J1417+1743	214.2783	17.7187	...	...	...	...	...	...	...	...	...	...	...
J1533+1500	233.4245	15.0165	...	...	...	...	...	...	...	...	...	...	...
J1500+1648	225.0874	16.8152	...	...	...	...	...	...	...	...	...	...	...
J1533+5650	233.3126	56.8458	...	...	...	...	...	...	...	...	...	...	...
J1059+0934	164.8402	9.5844	...	...	...	...	...	...	...	...	...	...	...
J0753+0822	118.3232	8.3719	...	...	...	...	...	...	...	...	...	...	...
J0925+3251	141.4070	32.8502	...	...	...	...	...	...	...	...	...	...	...
J0921+3243	140.4516	32.7330	...	...	...	...	...	...	...	...	...	...	...
J0914+3253	138.6990	32.8908	...	...	...	...	...	...	...	...	...	...	...

SDSS Name	RA	Dec	Plate	MJD	Fiber	z	u	g	r	i	z	W1	W2
J1035-0029	158.9373	-0.4902	...	...	...	...	...	...	...	...	...	...	...
J1053-0058	163.4703	-0.9813	...	...	...	...	...	...	...	...	...	...	...
J1056+0012	164.0902	0.2034	...	...	...	...	...	...	...	...	...	...	...
J1104-0004	166.1701	-0.0782	...	...	...	...	...	...	...	...	...	...	...
J1107-0051	166.8686	-0.8563	...	...	...	...	...	...	...	...	...	...	...
J1133-0057	173.4220	-0.9611	...	...	...	...	...	...	...	...	...	...	...
J1158-0043	179.7203	-0.7172	...	...	...	...	...	...	...	...	...	...	...
J1607+0058	241.9956	0.9711	...	...	...	...	...	...	...	...	...	...	...
J1716+6434	259.0158	64.5730	...	...	...	...	...	...	...	...	...	...	...
J1723+6547	260.8089	65.7962	...	...	...	...	...	...	...	...	...	...	...
J1733+5520	263.3785	55.3419	...	...	...	...	...	...	...	...	...	...	...
J1729+5547	262.2890	55.7857	...	...	...	...	...	...	...	...	...	...	...
J1725+5254	261.2527	52.9139	...	...	...	...	...	...	...	...	...	...	...
J1736+5855	264.2424	58.9172	...	...	...	...	...	...	...	...	...	...	...
J2339-0029	354.8934	-0.4924	...	...	...	...	...	...	...	...	...	...	...
J0321-0013	50.3167	-0.2230	...	...	...	...	...	...	...	...	...	...	...
J0925+0136	141.2972	1.6036	...	...	...	...	...	...	...	...	...	...	...
J1235+0132	188.9581	1.5536	...	...	...	...	...	...	...	...	...	...	...
J0857+5031	134.4673	50.5234	...	...	...	...	...	...	...	...	...	...	...
J1040+6122	160.2032	61.3792	...	...	...	...	...	...	...	...	...	...	...
J0849+0217	132.4738	2.2881	...	...	...	...	...	...	...	...	...	...	...
J1045+0540	161.3088	5.6675	...	...	...	...	...	...	...	...	...	...	...
J1432+0352	218.2217	3.8814	...	...	...	...	...	...	...	...	...	...	...
J1355+6152	208.7761	61.8694	...	...	...	...	...	...	...	...	...	...	...
J1507+5804	226.9116	58.0703	...	...	...	...	...	...	...	...	...	...	...

Note: The complete table with all data columns is available in the electronic version of this paper.

Note: Figure translations are in progress. See original paper for figures.