frontiers in Astronomy and Space Sciences

ORIGINAL RESEARCH
published: 22 November 2017
doi: 10.3389/fspas.2017.00040

SDSS J090152.05+624342.6: A NEW "OVERLAPPING-TROUGH" FeLoBAL QUASAR AT Z ∼ 2

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We here report an identification of SDSS J090152.04+624342.6 as a new "overlapping-trough" iron low-ionization broad absorption line quasar at redshift of $z \sim 2.1$. No strong variation of the broad absorption lines can be revealed through the two spectra taken by the Sloan Digital Sky Survey with a time interval of ∼6 yr. Further optical and infrared spectroscopic study on this object is suggested.

Keywords: quasars, broad absorption lines, spectroscopy, line identification, variability

OPEN ACCESS

Edited by:
Mauro D'Onofrio, Università degli Studi di Padova, Italy

Reviewed by:
Giovanna Maria Stirpe, Osservatorio Astronomico di Bologna (INAF), Italy
Daniela Bettoni, Osservatorio Astronomico di Padova (INAF), Italy

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Specialty section:
This article was submitted to Milky Way and Galaxies, a section of the journal Frontiers in Astronomy and Space Sciences

Received: *18 September 2017*
Accepted: *25 October 2017*
Published: *22 November 2017*

Citation:
Wang J, Xu D and Wei J (2017) SDSS J090152.05+624342.6: A NEW "OVERLAPPING-TROUGH" FeLoBAL QUASAR AT Z ∼ 2. Front. Astron. Space Sci. 4:40. doi: 10.3389/fspas.2017.00040

1. INTRODUCTION

Broad absorption line (BAL) quasars are the objects whose spectra show gas absorptions with a blueshfited outflow velocity from 2,000 km s^{-1} up to 0.1c (Weymann et al., 1991). Although the detailed physics of the outflow is still an open issue (e.g., Fabian, 2012), the outflow is believed to play an important role in the coevolution of the supermassive blackhole (SMBH) and its host galaxy, which is firmly established in local AGNs (see Heckman and Best, 2014 for a review) by either expelling circumnuclear gas (e.g., Kormendy and Ho, 2013; Woo et al., 2017) or triggering star formation through gas compressing (e.g., Zubovas et al., 2013; Ishibashi and Fabian, 2014).

Previous studies, especially the ones based on the Sloan Digital Sky Survey (SDSS, York et al., 2000), indicate that at low and intermediate redshift the fraction of BAL quasars is about 20–40% (e.g., Hewett and Foltz, 2003; Reichard et al., 2003; Trump et al., 2006; Dai et al., 2008; Knigge et al., 2008; Scaringi et al., 2009; Urrutia et al., 2009), depending on the selection method. About 90% of the BAL quasars are characterized by only high-ionized broad absorptions lines (HiBALs, e.g., CIV, SiIV, NV, OVI). The low-ionized absorption lines, such as MgII and AlIII, are identified in the so-called LoBAL quasars with a fraction of ∼10%. Among the LoBAL quasars, a small subset (∼ 1% of BAL quasars) of objects are classified as FeLoBAL quasars according to their FeII and/or FeIII absorption lines (Hazard et al., 1987; Hall et al., 2002; Brunner et al., 2003; Gibson et al., 2009; Zhang et al., 2010; Yi et al., 2017).

Although the physical origin of BAL quasars is originally ascribed to the orientation effect (e.g., Weymann et al., 1991; Goodrich and Miller, 1995; Gallagher et al., 2007), the higher reddening in BAL quasars than in non-BAL quasars motivate a lot of studies to try to understand if BAL quasars are young AGNs, in which the FeLoBAL quasars with the highest reddening and column density are possible transitional quasars from a dust-obscured AGN to a unobscured one. Mudd et al. (2017) recently identified the first post-starburst FeLoBAL quasar DES QSO J0330-28 at a redshift of 0.65.

In this paper, we report an identification of SDSS J090152.04+624342.6 as a new unusual FeLoBAL quasar with "overlapping-trough" (OFeLoBAL quasars) at $z \sim 2.1$.

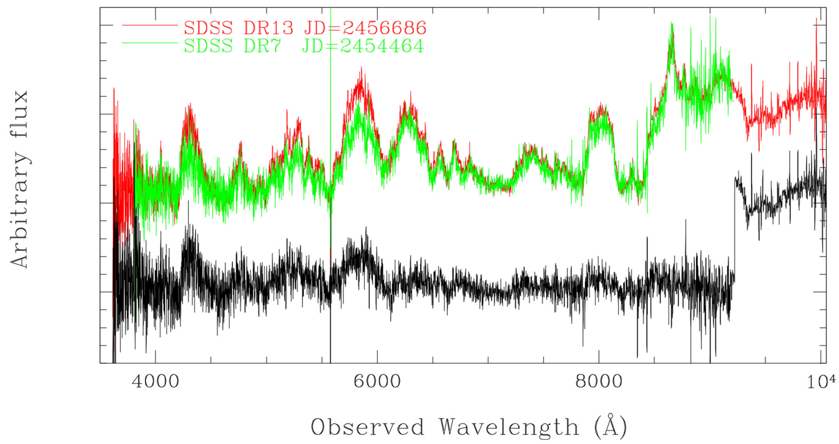

FIGURE 1 | The spectra taken from SDSS DR13 and that from SDSS DR7. Both spectra are shown in observer frame. The bottom black curve shows the differential spectrum that is vertically shifted by an arbitrary amount for visibility.

2. SPECTROSCOPIC IDENTIFICATION

2.1. History of SDSS J090152.04+624342.6

SDSS J090152.04+624342.6 was serendipitously extracted from the Sloan Digital Sky Survey (SDSS, York et al., 2000) Data Release 7 spectroscopic catalog, when we examined the spectrum of the "unknown" objects one by one **by eye.** The object was then classified as a quasar at $z = 2.09$ in the 7th SDSS Quasar Catalog (Schneider et al., 2010; Shen et al., 2011) by identifying the broad emission line at the red end as **MgII**λ2800. With a new spectroscopic observation, the redshift was recently (and improperly) updated to $z = 6.389420 \pm 0.000594$ by the pipelines of SDSS Data Release 13[1] through an identification of the peak as Lyα emission line. **Figure 1** shows the observer-frame spectrum of SDSS DR13 and that of DR7. In fact, by assuming a redshift of $z \sim 6$, the object shows abnormally significant emission blueward of the Lyman limit at observer frame wavelength of ∼6,500Å (see the typical spectra of the high-redshift quasars at $z \sim 6$ in Fan et al., 2006, Wu et al., 2015, Wang et al., 2017, Yang et al., 2017 and references therein).

2.2. Data Reduction

The spectral analysis is performed as follows by the IRAF packages[2]. The 1-Dimensional spectra of the object taken from SDSS DR13 is corrected for the Galactic extinction basing upon the V-band extinction taken from Schlafly and Finkbeiner (2011). An $R_V = 3.1$ extinction law (Cardelli et al., 1989) of the MilkyWay is adopted in the correction.

2.3. Identification of a New OFeLoBAL Quasar

Both spectra of the object taken from SDSS show an abrupt drops in flux at around the observer frame wavelength of $\lambda \sim 8,000$Å and many "features" blueward of the drop, which closely resemble the spectra of the unusual OFeLoBAL quasars discovered in previous studies, such as SDSS J0300+0048 ($z = 0.89$), SDSS J1154+0300 ($z = 1.458$), Mark 231, FIRST 1556+3517 and FBQS 1408+3054 (e.g., Smith et al., 1995; Becker et al., 1997, 2000; White et al., 2000; Hall et al., 2002). In the OFeLoBAL quasars, the abrupt drops are caused by a blueshifted absorptions due to MgII$\lambda\lambda$2796, 2803 and MgIλ2852, and almost no continuum windows can be identified blueward of the MgII emission because of the overlapping troughs mainly due to the FeII and FeIII absorptions.

Figure 2 shows the rest-frame spectrum of the object, along with our identification of both emission and absorption features. By ascribing the peak at the red end of spectrum as an emission from the MgII$\lambda\lambda$2796, 2803 doublets, the systematic redshift of the object is inferred to be $z = 2.09$ which is consistent with the previous claims in SDSS DR7 quasar catalog (e.g., Schneider et al., 2010; Shen et al., 2011; Wu et al., 2012). In fact, this redshift allows us to accurately **predict** the wavelength of not only the broad emission redward of the MgII emission, but also the CIVλ1549 and possible NeVλ1240 emission features, although the CIII]λ1909 emission commonly appearing in the quasar's spectra is hard to be identified in this object. The two bumps redward of the MgII emission are identified to be a blend of the HeIλ2945+FeIIλ2950 (UV60 and UV78) complex and a blend of the optical FeII complex at around 3,200Å (i.e., Opt7 and Opt6).

The spectrum blueward of the MgII emission is dominated by multiple overlapping troughs with a redshift of ∼1.98. Again, the redshift accurately predicts the wavelength of the absorptions blueward of the MgII emission. The onset of the troughs is a strong MgIλ2857 absorption followed by damped MgII$\lambda\lambda$2796, 2803 absorptions. An evident residual flux at high-velocity end of the MgII trough enables us to argue a presence of FeIIλ2750 (UV62 and UV63) absorptions, which is followed by the absorption features of FeII UV1 and UV2. With the redshift of ∼1.98, the troughs at middle of the spectrum

[1] http://www.sdss.org/dr13/data_access/bulk/

[2] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

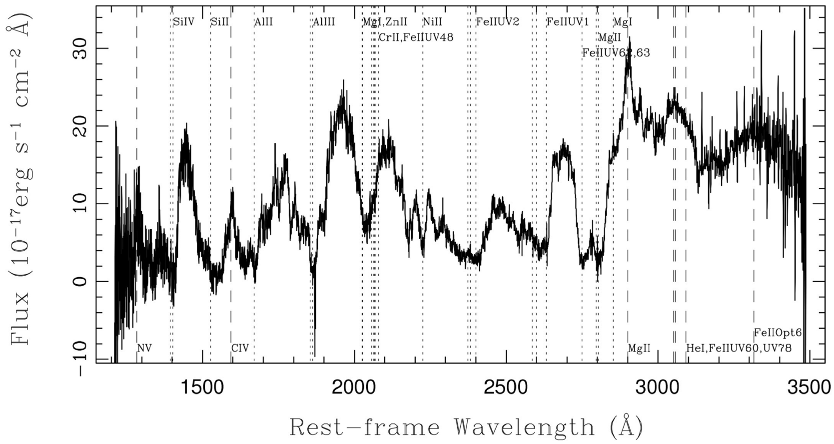

FIGURE 2 | The SDSS DR13 rest-frame spectrum of the object based on the redshift of the absorption features of $z = 1.98$. The long dashed lines from top to bottom marks the predicted wavelengths of the identified emission features, and the short dashed lines the wavelengths of the absorptions. The emission and absorption features are labeled at bottom and top of the figure, respectively.

are identified as the absorptions due to MgI+ZnII+CrII+FeII UV48, AlIII$\lambda\lambda$1854,1862 and AlIIλ1671, which are all common in the spectra of FeLoBAL quasars. Finally, two troughs due to SiIIλ1527 (UV2) and SiIV$\lambda\lambda$1394,1402 absorptions can be identified at the predicted wavelengths at the blue end of the spectrum.

3. NON-VARIATION OF THE NEW OFELOBAL QUASAR

Significant variation of BALs, including a complete disappearance, with a time scale of 1–10 year in the quasar rest-frame have been reported in the previous studies (e.g., Hall et al., 2011; Zhang et al., 2011, 2015; Filiz Ak et al., 2012, 2013; Vivek et al., 2012, 2014; Joshi et al., 2014). The significant variation can be explained by a variation of either the ionizing power (e.g., Trevese et al., 2013) or the covering factor due to a cloud transiting the line-of-sight (e.g., Hall et al., 2011). By comparing the variability of OFeLoBAL and non-OFeLoBAL quasars, Zhang et al. (2015) claimed a prevalence of strong BAL variation in the OFeLoBAL quasars rather than in the non-OFeLoBAL ones, which allows the authors to argue that the troughs in OFeLoBAL quasars are resulted from dense outflow gas closer to the central SMBH.

SDSS J090152.04+624342.6 has been observed twice by SDSS with a time interval of ∼6 yr, which corresponds to a rest-frame time of ∼2 yr. The two spectra are compared in **Figure 1**, along with a difference spectrum. The difference spectrum is obtained by a direct subtraction of the two spectra at the different epochs, since they are matched very well redward of the MgII line emission. One can see from the figure that no significant variation can be identified in the object through a comparison of the two SDSS spectroscopic observations. The invariant of the spectra of the object suggests a rest-frame life time of its BAL structure being no shorter than 2 yr. The knife-edge model in Capellupo et al. (2013) gives a simple relation of the crossing velocity υ of the absorber of $\upsilon_{\mathrm{cross}} = \Delta AD/\Delta t$, where ΔA is the fraction of the continuum region crossed by the absorber, and D the diameter of the continuum region. With the typical values of $\Delta A = 0.1$ and $D = 10^{-3}$pc (e.g., Capellupo et al., 2013; McGraw et al., 2015), the invariant of the BAL structure of the object within a rest-frame time of 2 yr suggests a crossing velocity $\upsilon_{\mathrm{cross}} < 5 \times 10^3$km s^{-1}.

4. CONCLUSION AND FUTURE STUDY

SDSS J090152.04+624342.6 is identified as a new OFeLoBAL quasar at $z \sim 2.1$. The spectra taken by SDSS at two epochs with a time interval of 6 yr do not show significant variation of its BAL. Further infrared spectroscopic observation is necessary for confirming the redshift determination, studying the host galaxy stellar population and estimating BH viral mass through Balmer emission lines. Based on the redshift of $z \sim 2.1$, the Hβ line which is traditionally used for BH mass estimation, is redshifted to 1.5μm at observer frame. And also, further optical spectroscopic and photometric monitor is useful for revealing significant BAL variation in the object.

AUTHOR CONTRIBUTIONS

JW initiated the study, conducted data reductions, and wrote the manuscript. DX and JYW contributed to the discussions and manuscript preparation.

FUNDING

This study is supported by the National Natural Science Foundation of China under grants 11473036 and 11773036, and by the National Basic Research Program of China (grant 2009CB824800).

ACKNOWLEDGMENTS

The authors would like to thank the referees for very useful comments and suggestions for improving the manuscript. This study uses the SDSS archive data that was created and distributed by the Alfred P. Sloan Foundation. The author would like to thank the referee from journal of ApJ letter who pointed out our initial mistake and gave us very useful suggestions.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.