

Changing-look Active Galactic Nuclei from the Dark Energy Spectroscopic Instrument. V. Dramatic Variability in High-Ionization Broad Emission Lines

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ABSTRACT

We present a systematic search for changing-look (CL) quasars at high redshift $z > 0.9$ by cross-matching the spectroscopic datasets from the Dark Energy Spectroscopic Instrument Data Release 1 and Sloan Digital Sky Survey Data Release 18. We identify 97 CL quasars showing significant variability in high-ionization broad emission lines (BELs), including 45 turn-on and 52 turn-off events, corresponding to a detection rate of $\sim 0.042\%$. The low rate relative to low-ionization CL quasars searches, likely due to selection and physical effects in high-ionization lines. Based on the CL quasar sample, we find that CL quasars generally exhibit lower accretion rates compared to typical quasars, with average Eddington ratios of $\log \lambda_{\text{Edd}} \sim -1.14$ in the bright state and ~ -1.39 in the dim state, compared to ~ -0.65 for typical quasars. Furthermore, while high-ionization lines in CL quasars follow the Baldwin effect on a population level, some sources can display inverse Baldwin trends. In addition, we find a positive correlation between the variability in high-ionization lines (e.g., Mg II, C III]) and the change in bolometric luminosity. We also estimate a characteristic rest-frame timescale of ~ 3 years for CL transitions, with no significant difference between turn-on and turn-off cases. Taken as a whole, these findings support an accretion-driven origin of the CL phenomenon, and provide new insights into the variability of high-ionization emission lines.

Keywords: Supermassive black holes (1663); Active galactic nuclei (16); Accretion (14); Spectroscopy (1558); Catalogs (205)

1. INTRODUCTION

Changing-look (CL) active galactic nuclei (AGNs) represent a rare subclass of AGNs characterized by the appearance (turn-on) or disappearance (turn-off) of broad emission lines (BELs) (LaMassa et al. 2015; Ruan et al. 2016; Yang et al. 2018; Trakhtenbrot et al. 2019; Zeltyn et al. 2022). This behavior poses a direct challenge of the standard unified model (UM) of AGNs, which attributes the observed diversity of AGN types primarily to orientation effects (Antonucci 1993; Urry & Padovani 1995). While changes in the accretion rate have been proposed as an intrinsic mechanism, where a significant drop could alter the central engine's structure, leading to the dimming or disappearance of the

broad-line region (BLR) and the transformation of the optically thick accretion disk into a radiatively inefficient accretion flow (Ho 2008). However, the observed transition timescales of CL AGNs, ranging from months to years, are often too rapid to be fully explained by existing theoretical models. Therefore, the nature of CL AGNs underscores the need for intrinsic physical changes within the AGN itself, the exact mechanisms of which remain a key open question in the field.

The physical mechanisms responsible for the optical CL phenomenon remain an active area of research. In the optical domain, where CL behavior is defined by the appearance or disappearance of BELs, two main categories of intrinsic explanations have been proposed: (1)

High-energy phenomena such as tidal disruption events (TDEs) that temporarily enhance accretion (Merloni et al. 2015; Blanchard et al. 2017; Li et al. 2022). However, the long-term light curves of most CL quasars are stochastic rather than exhibiting the rapid rise and slow decay trend typical of TDEs. (2) Abrupt changes in the accretion rate, potentially associated with state transitions in the accretion disk (MacLeod et al. 2019; Sniegowska et al. 2020; Jin et al. 2022; Yang et al. 2023), which represent the most widely accepted scenario. A key challenge here is that the observed transition timescales are much shorter than the theoretical viscous timescales of the disk, prompting the development of alternative models such as disk winds or an unstable disk (Matthews et al. 2020; Sniegowska et al. 2020). Although a few extreme cases have suggested that obscuration of the inner BLR by moving clouds or intervening material could be a potential mechanism (Zeltyn et al. 2022), this scenario is generally disfavored for most optical CL AGNs. Characteristic CL timescales, combined with infrared and polarimetric observations, often fail to support this interpretation (e.g., Sheng et al. 2017; Hutsemékers et al. 2019).

Early CL quasars were identified through visual inspection (e.g., LaMassa et al. 2015; Ruan et al. 2016; Yang et al. 2018). With the increasing availability of survey data, current searches for CL quasars mainly rely on two approaches: (1) direct comparison of spectroscopic emission lines (e.g., Zeltyn et al. 2024; Guo et al. 2024, 2025a; Dong et al. 2024), and (2) photometric variability searches in the optical or infrared to select candidates, followed by spectroscopic confirmation (e.g., Sheng et al. 2020; Green et al. 2022; López-Navas et al. 2023; Zhu et al. 2024; Yang et al. 2025; Chen et al. 2025). While CL quasars have been increasingly identified through variability in low- and intermediate-ionization BELs such as H α , H β , and Mg II (Ionization Potential, IP $\approx$ 7.6 eV), systematic studies of high-ionization BELs in CL transitions remain in their infancy. The few existing investigations underscore this gap: the identification of merely three CL quasars through C IV variability with $z > 2$ by Ross et al. (2020), a sample of 23 at $z > 1.5$ by Guo et al. (2020a), and the first-ever reported Ly α CL quasar by Guo et al. (2025b) collectively highlight the rarity and underexplored nature of the high-ionization CL phenomenon. These high-ionization lines such as C III] (IP $\approx$ 24.4 eV), C IV (IP $\approx$ 47.9 eV), and Si IV (IP $\approx$ 33.5 eV) arise from regions of the BLR closer to the central engine, where the ionization parameter is higher and the radiation pressure is more intense (e.g., Clavel et al. 1991; Netzer 2013). In addition, strong recombination lines like Ly α (IP = 13.6 eV), although not

a high-ionization line in the strict sense, also primarily originate in these inner BLR regions and can respond sensitively to rapid changes in the ionizing continuum. These lines are more responsive to changes in the ionizing continuum, therefore, systematic investigations of CL quasars involving high-ionization lines are crucial for probing rapid inner disk or accretion structure variations (Perez et al. 1992; Goad et al. 2016).

However, detecting CL behavior in these lines is challenging due to observational limitations at high redshift, such as low signal-to-noise ratios (SNR) and strong associated absorption features (Filiz Ak et al. 2013), as well as intrinsic physical effects such as the Baldwin effect, which suppresses equivalent widths as luminosity increases (Baldwin 1977; Shen et al. 2011). With the advent of large spectroscopic surveys such as the Dark Energy Spectroscopic Instrument (DESI; DESI Collaboration et al. 2016a) and the latest release of the Sloan Digital Sky Survey (SDSS; Almeida et al. 2023), it is now possible to explore high-redshift quasars with sufficient spectral depth and temporal baselines. In this work, we present a systematic search for high-redshift ($z > 0.9$) CL quasars based on spectral variability in high-ionization BELs. By cross-matching DESI Data Release 1 (DR1) and SDSS Data Release 18 (DR18) spectroscopic catalogs, and incorporating multi-epoch photometric data from the optical surveys, we build a robust selection pipeline that mitigates observational artifacts such as fiber drop and miscalibration.

The paper is structured as follows. In Section 2, we describe the datasets employed in this study, including both spectroscopic and photometric observations, along with the data preprocessing procedures. Section 3 describes the selection strategy for high-redshift CL quasars, and the criteria applied to ensure spectral reliability. In Section 4, the spectral decomposition approach is described. A comprehensive analysis of the CL quasar sample is carried out in Section 5, followed by a brief summary. Throughout this study, a concordance Λ CDM cosmology is adopted, with parameters $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (Spergel et al. 2003).

2. DATA

2.1. Spectroscopic Survey

The DESI is a Stage IV ground-based dark energy experiment conducted with the 4-meter Mayall Telescope at Kitt Peak National Observatory (Levi et al. 2013; DESI Collaboration et al. 2016a,b, 2022; Silber et al. 2023; Miller et al. 2024). It represents the most extensive multi-object spectroscopic survey to date, capable of simultaneously observing 5000 targets with robotic

fibers positioners on its focal plane and reaching an r -band limiting magnitude of ~ 23 . (DESI Collaboration et al. 2016a; Miller et al. 2024). In addition, the DESI spectrographs split the light into three channels: blue (3600-5900 Å), green (5660-7220 Å), and red (7470-9800 Å), with spectral resolutions of $R \sim 2100$, 3200, and 4100, respectively (DESI Collaboration et al. 2016b, 2022).

We also use the spectra from the SDSS. SDSS-V uses the Sloan Foundation 2.5m telescope located at the Apache Point Observatory in New Mexico, USA, and the du Pont 2.5m telescope at the Las Campanas Observatory in Chile (Gunn et al. 2006). The SDSS DR18 is the first data release of SDSS-V, encompassing all spectroscopic data from the previous four phases of the survey (Almeida et al. 2023). The SDSS spectra in the later three stages span a wavelength range of 3600 Å to 10600 Å, with a spectral resolution ranging from $R \sim 1300$ to ~ 3000 (Abazajian et al. 2004, 2009; Eisenstein et al. 2011; Smee et al. 2013).

Both the DESI and the SDSS spectroscopic pipelines compare the target spectra with galaxy, quasar, and star templates and classify the object as GALAXY, QSO, and STAR, automatically (Bolton et al. 2012; Hutchinson et al. 2016; Guy et al. 2023; Schlafly et al. 2023; DESI Collaboration et al. 2024a,b). During this work, we focus on objects that are classified as GALAXY or QSO. To ensure that the classification is reliable, we require the average SNR of the spectra to be larger than 2.

To facilitate the subsequent analysis, we perform pre-processing on the DESI and SDSS spectral data before their use. We corrected all spectra for Galactic extinction using the Fitzpatrick (1999) extinction law with $R_V = 3.1$, and subsequently shifted them to the rest frame. To directly subtract the spectra, we rebin the spectra onto a common wavelength grid with 2 Å per pixel.

2.2. Light Curve

The photometric light curves are essential for investigating the luminosity and color variations associated with CL behavior. Critically, they also enable checks for fiber drops and flux calibration (the detail is shown in Sec 3.1).

Accordingly, we incorporate long-baseline optical light curves from multiple surveys, including the Catalina Real-time Transient Survey (CRTS; V -band from 2005 to 2013; Drake et al. 2009, 2012), the Pan-STARRS1 (PS1; g - and r -band from 2010 to 2014; Chambers et al. 2016), and the Zwicky Transient Facility (ZTF; g - and r -band; Bellm et al. 2019; Masci et al. 2019) for the optical band. We specifically utilize the ZTF DR23 for

data from 2018 to the present, which provides forced-photometry light curves from the ZTF Public Sky Survey. We performed several data quality cuts to ensure the reliability of the light curves. First, we discarded data points with photometric errors larger than twice the average error of the long-term light curve. Second, we applied a 3σ clipping algorithm twice to remove statistical outliers. Finally, to mitigate the impact of correlated noise and systematic errors, we binned the data into 3-day intervals, following the methodology of Masci et al. (2019) and Green et al. (2022). We caution that analyses near the survey limits require care because the limiting magnitudes of these surveys vary slightly. For example, the CRTS has a V -band limiting magnitude of approximately 20.5, while PS1 reaches about 22.0 in the g -band and 21.8 in the r -band. For ZTF, the limiting magnitudes are around 20.8 and 20.5 in the g - and r -bands, respectively (Drake et al. 2009, 2012; Tonry et al. 2012; Bellm et al. 2019; Masci et al. 2019).

3. SAMPLE SELECTION AND RESULT

3.1. Sample Selection

Based on previous works (Guo et al. 2024, 2025a), we select targets with redshifts $z > 0.9$ to ensure that key high-ionization emission lines are in the observed wavelength range and sufficiently separated from the spectral edge of the detector, where the SNR is critically low. We then perform a positional cross-match between the pre-selected DESI DR1 and SDSS DR18 spectroscopic catalogs. To ensure the matches are astrophysically relevant and minimize false positives, we adopt a matching radius of 1 arcsecond and further require a redshift difference of $|\Delta z| < 0.01$. From these robust matches, we keep sources classified as QSO in one epoch and GALAXY or QSO in the other. In our final sample, we keep 826 pairs of non-repeated GALAXY-QSO and 228,623 pairs of QSO-QSO. SDSS-V has already conducted systematic comparisons of repeat spectra to search for CL quasars (e.g., Zeltyn et al. 2024), and since the DESI time baselines are relatively short, we retain only the latest spectrum per source in each survey to avoid redundancy.

To efficiently identify a robust sample of CL candidates from the parent sample, we employ a set of spectral variability metrics that probe both the statistical significance and the physical magnitude of BEL changes. Our methodology follows and extends the work of MacLeod et al. (2016) and Guo et al. (2024), focusing on three key parameters.

First, we quantify the statistical significance of the spectral change at each wavelength pixel using an SNR metric:

$$N_\sigma(\lambda) = (f_{\text{bright}} - f_{\text{dim}}) / \sqrt{\sigma_{\text{bright}}^2 + \sigma_{\text{dim}}^2}, \quad (1)$$

here, $N_\sigma(\lambda)$ represents the significance of the flux difference between the bright- and dim-state spectra, where the f and σ are the flux and uncertainty at λ in $\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$. This parameter allows us to identify regions of the spectrum where the change is robust against observational noise.

Second, to measure the physical magnitude of the change in the BELs, we define a continuum-subtracted integrated flux ratio, R :

$$R = \frac{F_{\text{bright}} - F_{\text{dim}}}{F_{\text{dim}}}, \quad (2)$$

where F represents the total integrated flux of a specific BEL, obtained by summing the continuum-subtracted flux within the rest-frame windows listed in Table 1. The uncertainty σ_R is calculated using the propagation of the standard error. However, a large R value alone could be misleading if the line is barely detected in the dim state. To ensure that a disappearing line is genuinely absent and not merely diluted, we introduce a third parameter, $F_{\sigma, \text{dim}}$, to quantify the prominence of the emission line in the dim state:

$$F_{\sigma, \text{dim}} = \sum f_{\text{dim}} / \sqrt{\sum \sigma_{\text{dim}}^2}. \quad (3)$$

This is effectively the integrated SNR of the line in the dim-state spectrum.

In summary, our candidate selection leverages these complementary metrics: $N_\sigma(\lambda)$ maps significant spectral changes, R quantifies the amplitude of the BEL flux change, and $F_{\sigma, \text{dim}}$ confirms the line's non-detection in the dim state. This multi-faceted approach minimizes false positives caused by poor data quality while effectively capturing genuine CL events.

We adopt stricter selection criteria than previous works (e.g., Guo et al. 2024), requiring $N_\sigma(\lambda) > 3$ and $R > 2$ to ensure significant variability in the BELs, and we imposed $R > 2\sigma_R$ to guarantee the reliability of our total broad-line flux measurements. Finally, we required $F_{\sigma, \text{dim}} < 2R$, which ensures that the emission lines are relatively weak in the dim state. At this step, a total of two GALAXY-QSO pairs and 572 QSO-QSO pairs satisfy the criteria.

As mentioned in previous studies, the flux calibration or fiber drop issues may affect the assessment of variability of BELs (e.g., Guo et al. 2020a, 2024). The most common method for calibrating the relative flux scaling of two spectra assumes that the narrow emission line [O III] (5007 Å) remains constant over timescales of a few years (e.g., Margala et al. 2016; Wang et al. 2024b),

as the narrow-line region typically extends over kiloparsec scales, so significant variations in narrow lines would only occur over millennial timescales (Bennert et al. 2002; Dempsey & Zakamska 2018). However, this approach is unsuitable for high-redshift sources, as the prominent narrow lines are shifted beyond the observational windows of SDSS and DESI. To mitigate contamination from flux calibration errors or fiber drop effects, we compute pseudo-magnitude by convolving each spectrum with the g -, r - and V -band filter transmission curves and compare them to the photometric magnitudes measured at the corresponding epochs in the light curves. Spectra with > 0.5 mag discrepancy are excluded unless verified visually (see Figure 11 and Appendix A). In total, we excluded 326 spurious sources attributed to fiber drop issues.

Since the limiting magnitudes of ZTF and PS1 in the g -band are 20.8 mag and 23.0 mag, respectively, therefore, for sources with magnitudes fainter than 21 mag, we take extra caution. Instead of directly comparing them with the observational magnitude, we scale the two spectra to the same photometric level before examining the differences in their emission lines and do a visual check for them to confirm that the CL phenomenon is not due to the fiber drop in Section 3.2.

3.2. Visual Check

For high-redshift CL quasars, visual inspection is a key step for identification, as it avoids the need for complex spectral decomposition. This is particularly important because the high-redshift spectra typically have relatively low SNR. In addition, the impact of interstellar medium and AGN outflows on BELs cannot be ignored, variable AGN outflows on BELs cannot be ignored, especially for C IV and Ly α (e.g., Wolfe et al. 1986; Filiz Ak et al. 2013). Strong and variable absorption from outflows, such as those in broad absorption line quasars, can not only affect continuum subtraction, leading to incorrect flux estimates, but can also produce observed spectral changes that might be mistaken for intrinsic CL behavior if the outflow structure varies between epochs (e.g., Capellupo et al. 2011; Aromal et al. 2022).

Here, we perform visual inspections on all sources that meet the criteria outlined in Section 3.1. First, we check whether strong absorption lines are present within the integration windows of the emission lines of interest. Sources with such absorption lines are discarded unless they exhibit a transition from emission to absorption lines. Secondly, we exclude sources without clear CL signatures as these may result from inaccurate emission line measurements due to low SNR or improper continuum subtraction. Thirdly, a small fraction of sources with

Table 1. The integration windows for BELs

Line Name	Wavelength (Å)	Window (Å)	Left Continuum (Å)	Right Continuum (Å)
(1)	(2)	(3)	(4)	(5)
Ly α	1215.67	1190–1250	1150–1190	1250–1290
Si IV	1396.76, 1402.77	1360–1430	1310–1360	1430, 1480
C IV	1548.19, 1550.77	1510–1590	1460–1510	1590–1640
C III]	1906.68, 1908.73	1850–1970	1820–1850	1970–2000
Mg II	2795.53, 2802.71	2750–2850	2680–2720	2880–2920

NOTE—Column (1): BEL name; Column (2): Rest wavelength of the BEL; Column (3): Integration window of the BEL; Column (4): Left continuum window of the BEL; Column (5): Right continuum window of the BEL.

inconsistent redshifts between SDSS and DESI spectra are excluded. Finally, we check that the sources with pseudo-magnitudes fainter than 21 mag and the magnitude difference larger than 0.5 mag (the outliers in Figure 1), to determine whether the faintness is intrinsic or caused by fiber drop. This is primarily done by examining changes in the spectral shape, since genuine CL transitions are typically accompanied by variations in the continuum (e.g., Yang et al. 2018; Guo et al. 2025a). On the other hand, we perform visual inspection to distinguish CL quasars, characterized by the appearance or disappearance of BELs, and CL quasar candidates, which show dimmer spectra but still retain weak BELs. Such sources may have been caught in a transitional phase of CL behavior when the dim-state spectrum was taken, and are, therefore, classified as CL quasar candidates (e.g., Guo et al. 2019b).

To provide a clearer overview of our sample selection process, we summarize the main selection criteria and corresponding sample sizes in Table 2. Each row represents a major step in the filtering procedure, starting from 229,449 matched spectroscopic pairs from SDSS DR18 and DESI DR1, we sequentially applied our criteria: a significance cut ($N_\sigma(\lambda) > 3$) retained 145,171 pairs; a broad line flux ratio cut ($R > 2$) selected 697 pairs; a dim-state line prominence cut ($F_{\sigma,\text{dim}} < 2R$) yielded 574 pairs; and a final pseudo-magnitude filter (< 0.5 mag) identified 248 high-probability candidates. After visual inspection of these candidates, we secured a final sample of 97 robust CL quasars and 135 additional CL quasar candidates, while flagging 16 targets as false positives.

3.3. Result

In this work, we identified 97 high-redshift CL quasars from 826 pairs of GALAXY-QSO and 228,623 pairs of QSO-QSO, comprising 45 turn-on and 52 turn-off events. Figure 2 shows their luminosity and redshift distributions, which are broadly consistent with the overall SDSS quasar population at similar redshifts (Rakshit et al. 2020). In terms of luminosity, even when CL quasars are in their bright state, their median luminosity ($\log L_{\text{bol}} = 45.95 \pm 0.043$) is slightly lower than that of typical quasars at the same redshift range (median $\log L_{\text{bol}} = 46.03 \pm 0.001$). However, in either bright or dim state (median $\log L_{\text{bol}} = 45.71 \pm 0.041$ for the dim state), CL quasars are still more luminous than normal AGNs, reaching quasar-level luminosities ($L \gtrsim 10^{45}$ erg s $^{-1}$). This is largely due to selection effects, as fainter objects at $z > 0.9$ fall below the SDSS detection limits. Uncertainties on median values are estimated via bootstrap resampling with 1,000 iterations.

Previous systematic studies have shown that the number of turn-on and turn-off CL quasars is roughly equal (e.g., MacLeod et al. 2016; Guo et al. 2025a; Wang et al. 2024a). In our high-redshift sample, the ratio is 1 : 1.15, with a slight excess of turn-off sources. This could be attributed to differences in survey depth, as DESI is significantly deeper than SDSS. Some faint sources may only be detectable in DESI, causing high-redshift turn-on CL quasars to remain undetected in the dim state because of the limited sensitivity of SDSS. In the final CL quasar sample, we identify 28 sources exhibiting CL behavior in the Mg II emission line. The C III] line is the most frequently affected, with 59 CL cases. CL behavior is also observed in 25 CIV and 26 Si IV sources. Additionally, we report 8 CLAGNs showing transitions in the Ly α line. Note that some of these cases are overlapping, as a single target may exhibit the CL phenomenon in multi-

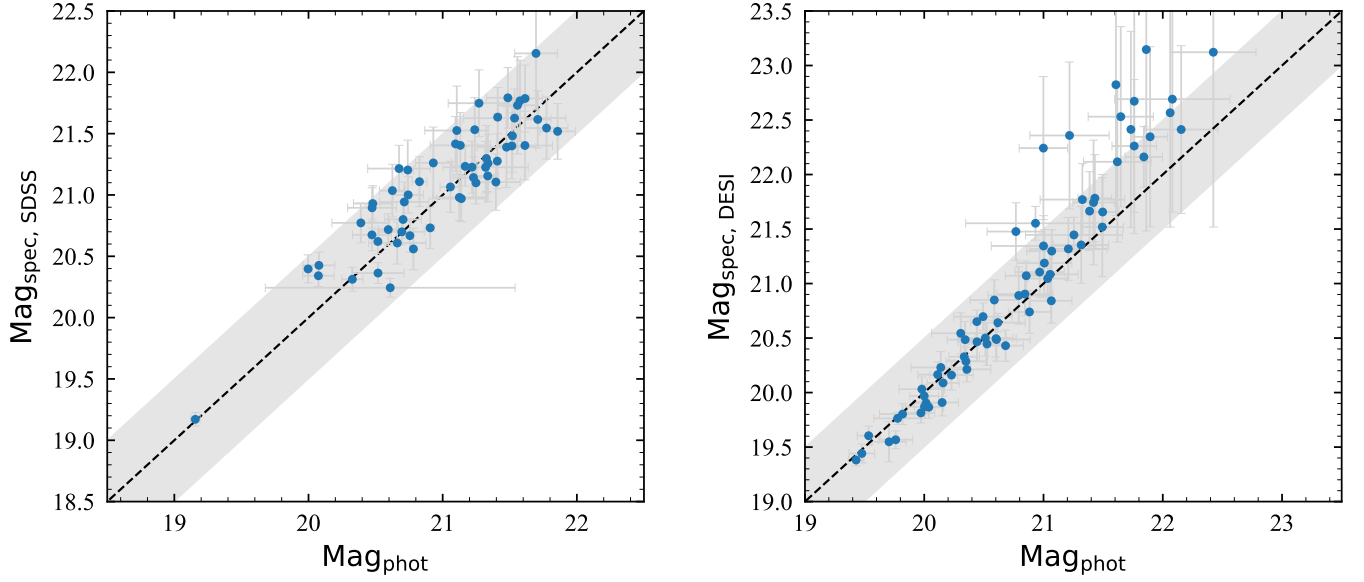


Figure 1. The pseudo-magnitude of our CL quasars versus the actual brightness from several photometric surveys simultaneously. The left and right panels show the magnitude of the targets at the SDSS and DESI observational epochs, respectively. The shaded region indicates an uncertainty range of 0.5 mag.

Table 2. CL quasars selection from matching the SDSS DR18 and DESI DR1

Selection	N_{object}
class=QSO and spectype=GALAXY class=GALAXY and spectype=QSO class=QSO and spectype=QSO	229,449 pairs
$N_{\sigma}(\lambda) > 3$	145,171 pairs
$R > 2$	697 pairs
$F_{\sigma, \text{dim}} < 2R$	574 pairs
pseudo-magnitude < 0.5 mag	248 pairs
visual check	16 fake targets 97 CL quasars 135 CL quasar candidates

ple emission lines. In Figure 3, we present representative examples of the CL phenomenon for each emission line, illustrating clear cases of BEL appearance or disappearance. In addition, we cross-match the sample with the Faint Images of the Radio Sky at Twenty-Centimeters (FIRST) catalog¹ and find that the vast majority of CL quasars are radio-quiet, with only three sources having radio fluxes above the detection threshold of the FIRST survey (Becker et al. 1995; Helfand et al. 2015). We will

conduct a follow-up analysis on the radio properties of CL quasars in future work. The entire CL quasar sample identified in this work is shown in Table 3.

Moreover, we identified 135 CL quasar candidates that appear to be in intermediate stages of the CL process. These sources are crucial for probing the physical mechanisms behind CL quasars, such as the continuous evolution of accretion rates and the sequence of emission-line transitions (e.g., Trump et al. 2011; Panda & Śniegowska 2024). Figure 4 shows a CL quasar candidate identified

¹ <http://sundog.stsci.edu/>

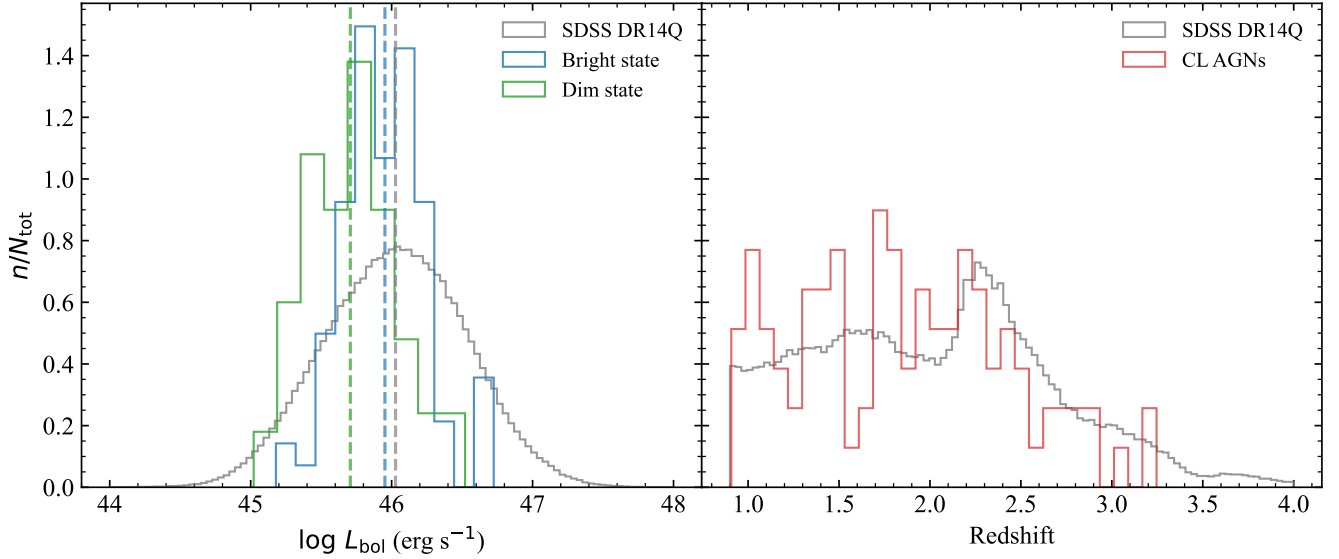


Figure 2. The luminosity and redshift distribution of the high-redshift CL quasars in this work. The grey histogram is the quasar sample at the same redshift range from the SDSS DR14 QSO catalog (Rakshit et al. 2020). The corresponding dashed lines in the left panel represent the average values.

in the C III] line. The entire CL quasar candidate sample is shown in Appendix B.

4. SPECTRAL FITTING

To extract the physical parameters for CL quasars, we adopt the PyQSOFit² to perform spectral decomposition (Shen et al. 2019; Guo et al. 2019a; Ren et al. 2024a). During the fitting procedure, we ignore the host galaxy component, as its contribution is negligible compared to that of the central black hole in high-redshift objects. This is a standard approach in spectral analyses of high-redshift samples, as demonstrated in previous studies (e.g., Shen et al. 2011; Guo et al. 2020a). We model the line-free continuum using a combination of a power-law, a third-order polynomial, and a pseudo-continuum constructed from UV/optical Fe II emission templates. After subtracting the best-fit AGN continuum model, we separate BELs and narrow emission lines using a full width at half maximum (FWHM) threshold of 1200 km s^{-1} . The narrow lines are modeled using single Gaussian profiles, as they typically originate from a spatially distinct, dynamically cold region with well-defined velocity dispersion. For the broad components, we allow a maximum of three Gaussians to better de-

scribe the asymmetry. The specific number of Gaussian components adopted for each broad emission line is fixed for all sources in our sample, as shown in Table 4. This strategy is chosen to ensure a consistent and homogeneous analysis pipeline crucial for robust statistical comparisons. These numbers are not determined on a source-by-source basis but are instead based on the established practice of previous systematic studies (e.g., Shen et al. 2011; Guo et al. 2019a, 2020a; Ren et al. 2024b). These studies identified the optimal number of components for various emission lines using the Bayesian Information Criterion, which determines the preferred model by evaluating the trade-off between goodness-of-fit and model complexity. The cited studies systematically compared models with increasing numbers of Gaussians and selected the one that provided a significantly better fit without overfitting. Consequently, the number of Gaussians varies for different lines, reflecting their distinct intrinsic kinematics and profile shapes. Highly asymmetric lines with prominent broad wings or blue shift, such as Ly α and C IV, are typically modeled with three Gaussians. In contrast, lines with generally more symmetric profiles, such as Si IV, C III], and Mg II, are adequately fitted with two Gaussian components to prevent overfitting. Finally, we estimate the uncertainties of the fitted parameters through 200 Monte Carlo realizations, where each pixel is perturbed by Gaussian noise scaled to its measurement error.

² <https://github.com/legolason/PyQSOFit>

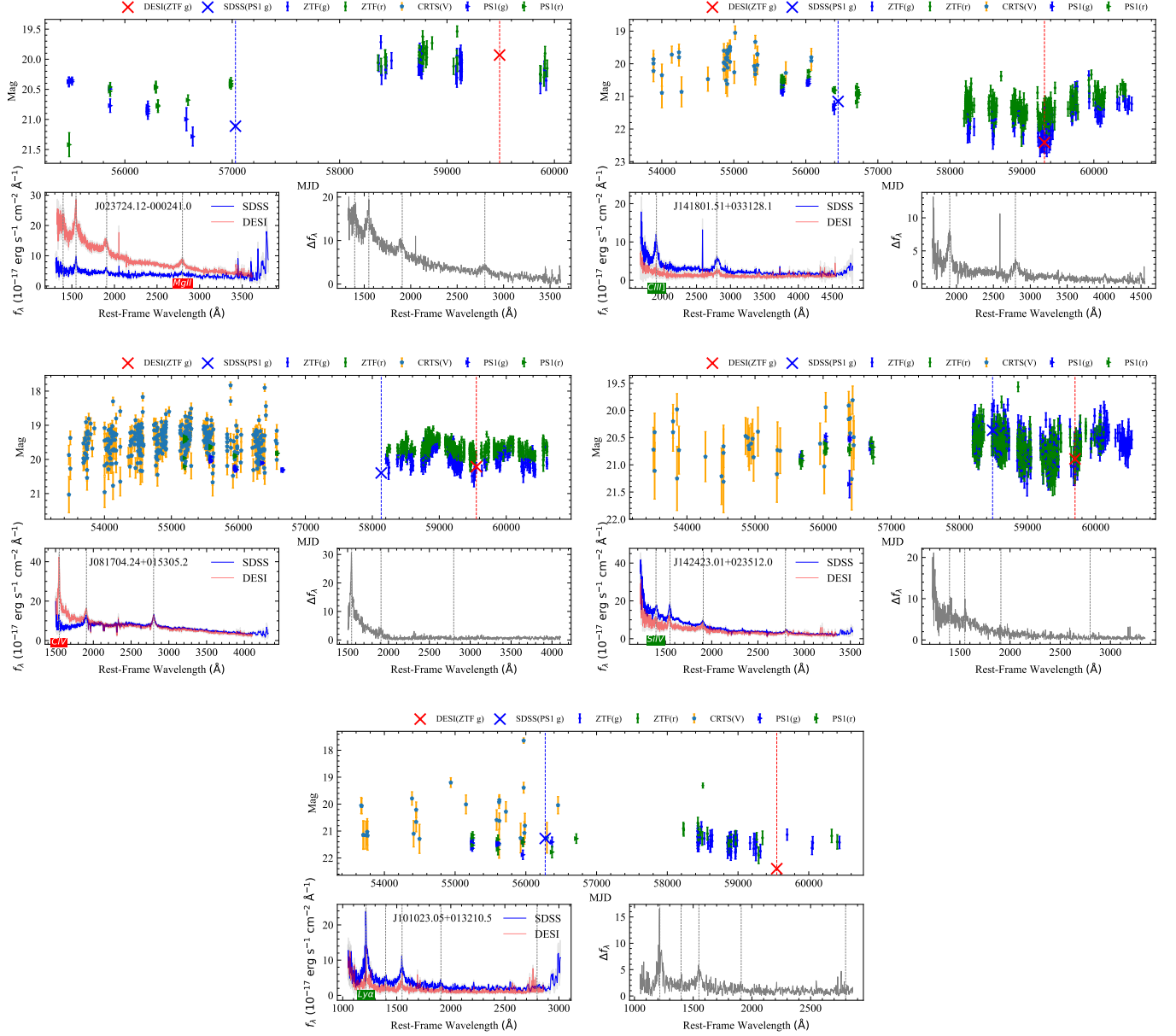


Figure 3. Five examples of CL quasars showing significant transitions in different emission lines. For each example, the top panel shows the nearly 20-year light curve compiled from CRTS V-band (dark blue pentagons), PS1 g -band (blue triangles), r -band (green triangles), ZTF g -band (blue circles), and r -band (green circles). The blue and red dashed vertical lines indicate the epochs of SDSS and DESI spectroscopic observations, respectively. The corresponding “X” markers represent the pseudo-magnitudes derived by convolving the spectra with filter response curves. The bottom-left panel displays the original spectra from SDSS (blue) and DESI (red). Red and green squares at the bottom denote detected turn-on and turn-off transitions, respectively. The lower-right panel shows the difference in flux between the two spectra. Gray dashed lines in the bottom panels mark the expected positions of key emission lines.

Table 3. Fits Catalog Description and Column Information of CL quasars in this work.

Number	Column Name	Format	Unit	Description
(1)	(2)	(3)	(4)	(5)
0	SDSS_NAME	string		Unique identifier of SDSS object
1	R.A.	float32	degree	Right Ascension (J2000)
2	Dec.	float32	degree	Declination (J2000)
3	Redshift	float32		Redshift
4	MJD_SDSS	int		MJD of the SDSS spectrum
5	MJD_DESI	float32		Mean MJD of the coadded DESI spectra
6	Transition	string		Changing state between SDSS and DESI spectra
7	MgII_state	string		State change in Mg II
8	CIII_state	string		State change in C III]
9	CIV_state	string		State change in C IV
10	SiIV_state	string		State change in Si IV
11	Lya_state	string		State change in Ly α
12	LOGLBOL_Bri	float32	erg s ⁻¹	Bolometric luminosity in the bright state
13	LOGLBOL_Bri_ERR	float32	erg s ⁻¹	Error in LOGLBOL_Bri
14	LOGLBOL_Dim	float32	erg s ⁻¹	Bolometric luminosity in the dim state
15	LOGLBOL_Dim_ERR	float32	erg s ⁻¹	Error in LOGLBOL_Dim
16	EW_MgII_Bri	float32	Å	EW of Mg II (bright)
17	EW_MgII_Bri_ERR	float32	Å	Error in EW_MgII_Bri
18	EW_MgII_Dim	float32	Å	EW of Mg II (dim)
19	EW_MgII_Dim_ERR	float32	Å	Error in EW_MgII_Dim
20	EW_CIII_Bri	float32	Å	EW of C III] (bright)
21	EW_CIII_Bri_ERR	float32	Å	Error in EW_CIII_Bri
22	EW_CIII_Dim	float32	Å	EW of C III] (dim)
23	EW_CIII_Dim_ERR	float32	Å	Error in EW_CIII_Dim
24	EW_CIV_Bri	float32	Å	EW of C IV (bright)
25	EW_CIV_Bri_ERR	float32	Å	Error in EW_CIV_Bri
26	EW_CIV_Dim	float32	Å	EW of C IV (dim)
27	EW_CIV_Dim_ERR	float32	Å	Error in EW_CIV_Dim
28	FWHM_MgII_Bri	float32	km s ⁻¹	FWHM of Mg II (bright)
29	FWHM_MgII_Bri_ERR	float32	km s ⁻¹	Error in FWHM_MgII_Bri
30	FWHM_MgII_Dim	float32	km s ⁻¹	FWHM of Mg II (dim)
31	FWHM_MgII_Dim_ERR	float32	km s ⁻¹	Error in FWHM_MgII_Dim
32	FWHM_CIV_Bri	float32	km s ⁻¹	FWHM of C IV (bright)
33	FWHM_CIV_Bri_ERR	float32	km s ⁻¹	Error in FWHM_CIV_Bri

Table 3. (Continued)

Number	Column Name	Format	Unit	Description
(1)	(2)	(3)	(4)	(5)
34	FWHM_CIV_Dim	float32	km s ⁻¹	FWHM of C IV (dim)
35	FWHM_CIV_Dim_ERR	float32	km s ⁻¹	Error in FWHM_CIV_Dim
36	Flux_MgII_Bri	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Flux of Mg II in the bright state
37	Flux_MgII_Bri_ERR	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Error in Flux_MgII_Bri
38	Flux_MgII_Dim	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Flux of Mg II in the dim state
39	Flux_MgII_Dim_ERR	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Error in Flux_MgII_Dim
40	Flux_CIII_Bri	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Flux of C III] in the bright state
41	Flux_CIII_Bri_ERR	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Error in Flux_CIII_Bri
42	Flux_CIII_Dim	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Flux of C III] in the dim state
43	Flux_CIII_Dim_ERR	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Error in Flux_CIII_Dim
44	Flux_CIV_Bri	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Flux of C IV in the bright state
45	Flux_CIV_Bri_ERR	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Error in Flux_CIV_Bri
46	Flux_CIV_Dim	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Flux of C IV in the dim state
47	Flux_CIV_Dim_ERR	float32	10 ⁻¹⁷ erg s ⁻¹ cm ²	Error in Flux_CIV_Dim
48	LOGMBH	float32	$M_{\odot}$	The adopted fiducial black hole mass
49	LOGMBH_ERR	float32	$M_{\odot}$	Error in LOGMBH
50	LOGREDD_Bri	float32		Logarithmic Eddington ratio in the bright state
51	LOGREDD_Bri_ERR	float32		Error in LOGREDD_Bri
52	LOGREDD_Dim	float32		Logarithmic Eddington ratio in the dim state
53	LOGREDD_Dim_ERR	float32		Error in LOGREDD_Dim
54	Radio_Flux	float32	mJy	Radio flux at 1.4 GHz in FIRST catalog

NOTE—We provide the basic information and the main spectral fitting result of the high-redshift CL quasars identified in this work. The unmeasurable parameters are set to -999. The errors are obtained from 200 iterations of the Monte Carlo simulation.

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

It is worth noting that high-ionization emission lines are often accompanied by broad or narrow absorption features, which can significantly affect the continuum subtraction and emission-line fitting. To mitigate this, we follow the method proposed by Guo et al. (2020a) to mask potential absorption features before the fitting (see Section 3.4 of their paper for details). Here, we show a fitting example in Figure 5.

5. DISCUSSION

5.1. Detection Rate

CL quasars are an extremely rare and peculiar class of objects, with high-redshift CL quasars being even more scarce. Previous studies report CL quasar detec-

tion rates of roughly 0.3 ~ 1% from both spectroscopic comparisons and variability-based searches (e.g., López-Navas et al. 2023; Wang et al. 2024b; Dong et al. 2024; Guo et al. 2025a). We identify 97 CL quasars from a parent sample of 229,449 matched spectral pairs at $z > 0.9$, yielding a detection rate of ~0.042%. This rate is approximately an order of magnitude lower than those reported in previous works, which typically focus on low-ionization lines or rely on higher SNR observations (e.g., Dong et al. 2024; Guo et al. 2025a). This lower detection rate is attributable either to selection effects or to intrinsic differences. On the selection side, a key factor is sample flux limits. The intrinsically higher luminosities of high-redshift CL quasars, though generally

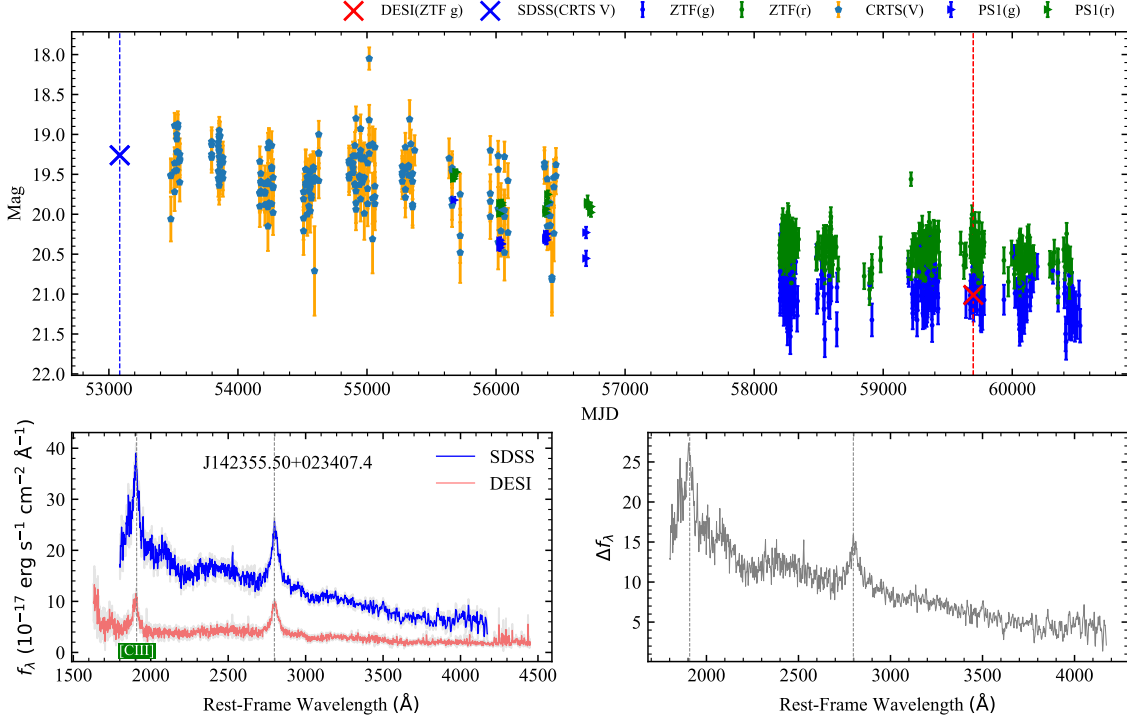


Figure 4. An example of a CL quasar candidate. The panel layout and symbols are the same as in Figure 3.

bright, can drop below the detection limits of the surveys during their faint phase, causing some targets to be missed. In addition, CL transitions occur on timescales of months to years in the rest frame, with reported median values of about 10 years (the detail is shown in Section 5.5). Due to cosmological time dilation, some longer-timescale CL transitions are stretched in the observation frame beyond the temporal baselines of SDSS and DESI (~ 20 yr), and thus cannot be captured within the available observations. On the intrinsic side, high-ionization emission lines (e.g., Mg II, C IV) generally follow the Baldwin effect (Baldwin 1977; Ren et al. 2024b), whereas the definition of CL quasars inherently makes them a special population that tends to exhibit an inverse Baldwin effect (the detail is shown in Section 5.4). As a result, CL behavior involving high-ionization lines is expected to be rarer than that involving low-ionization lines. Moreover, high-redshift quasars are observed near the so-called “cosmic noon”, when quasar activity is at its peak; the high average accretion rates during this epoch may reduce the fraction of sources undergoing dramatic state changes.

5.2. Eddington Ratio

The Eddington ratio is a critical parameter to explore the physical mechanism of the CL quasars. Before mea-

suring the Eddington ratio, we first calculate the mass of the black hole. Here, we assume a virialized BLR and estimate the black hole mass following Shen et al. (2011):

$$\log\left(\frac{M_{\text{BH}}}{M_{\odot}}\right) = a + b \log\left(\frac{\lambda L_{\lambda}}{10^{44} \text{ erg s}^{-1}}\right) + 2 \log\left(\frac{\text{FWHM}}{\text{km s}^{-1}}\right), \quad (4)$$

where the values of parameters a and b vary for different emission lines in the virial black hole mass estimation. For sources with reliable Mg II measurements ($\text{SNR} > 2$), we estimate black hole masses using the FWHM of the Mg II broad emission line and the monochromatic luminosity at 3000 Å in the bright state, with coefficients $a = 0.740$ and $b = 0.62$ (Shen et al. 2011). For the remaining sources, either due to the Mg II line falling outside the spectral coverage or having low SNR, we instead adopt the C IV line in the bright spectra, using L_{1350} as the continuum luminosity and coefficients $a = 0.66$ and $b = 0.53$ (Vestergaard & Peterson 2006).

The bolometric luminosity can be derived from the continuum luminosity using bolometric corrections $L_{\text{bol}} = 5.15 L_{3000}$ or $L_{\text{bol}} = 3.81 L_{1350}$, following Richards et al. (2006). Based on the black hole mass

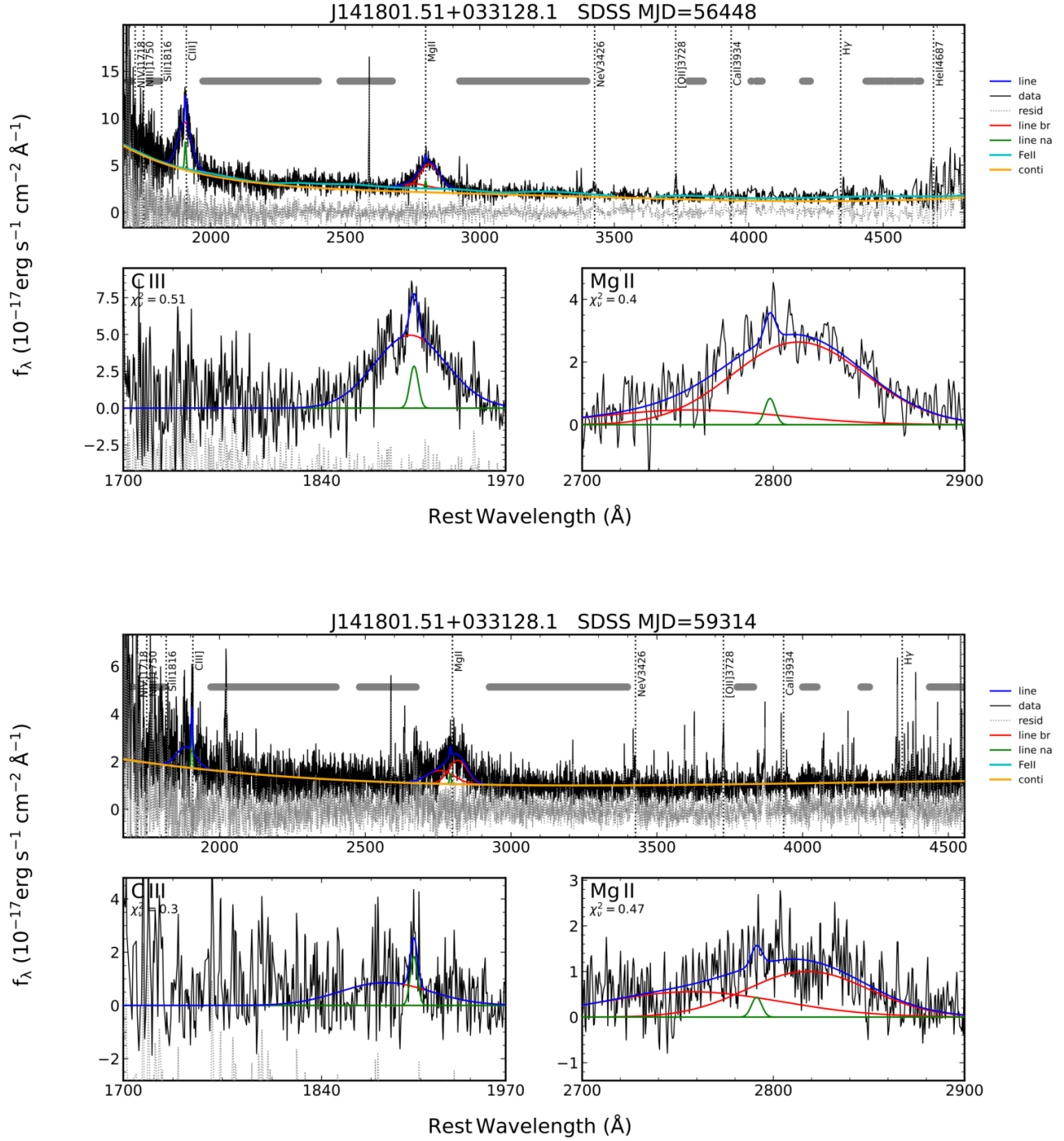


Figure 5. Example of spectral fitting for the bright (SDSS, top panel) and dim (DESI, bottom panel) states of J141801.51 + 033128.1 using PyQSOFit. The observed spectrum (black) is decomposed into an AGN power-law continuum (orange) and an Fe II emission template (cyan) in the upper panel, under the assumption that the host galaxy contribution is negligible. Emission lines are shown in blue and are further decomposed into broad (red) and narrow (green) components. The lower panel provides a zoomed-in view.

Table 4. The fitting parameters for emission lines

Line	Complex Fitting Window ($\text{\AA}$)	Line Name	N_{gaussian}
(1)	(2)	(3)	(4)
Ly α	1150-1290	Broad Ly α	3
		N v 1240.14	1
Si IV	1290-1450	Si IV/O IV]	2
		O IV 1304.35	1
		C II 1335.30	1
		Broad C IV	3
C IV	1500-1700	Broad He II 1640.42	1
		Narrow He II 1640.42	1
		Broad O III 1663.48	1
		Narrow O III 1663.48	1
		Broad C III]	2
		[N IV] 1718.55	1
		[N III] 1750.26	1
		[Fe II] 1786.7	1
C III]	1700-1970	[Si II] 1816.98	1
		Al III 1857.40	1
		Si III] 1892.03	1
		Broad Mg II	2
		Narrow Mg II 2798.75	1
Mg II	2700-2900	Broad Mg II	2
		Narrow Mg II 2798.75	1

estimated from the bright-state spectrum, we then calculate the Eddington ratios for both the bright and dim states:

$$\lambda_{\text{Edd}} = \frac{L_{\text{bol}}}{L_{\text{Edd}}} = \frac{L_{\text{bol}}}{1.26 \times 10^{38} M_{\text{BH}}/M_{\odot}}. \quad (5)$$

Figure 6 presents the distribution of our CL quasar sample in the $L_{\text{bol}}/L_{\text{Edd}}-M_{\text{BH}}$ plane, in comparison with SDSS quasars at $z > 0.9$ and a local CL quasar sample ($z < 0.3$) from Guo et al. (2025a). Compared to typical quasars (median $\log \lambda_{\text{Edd}} = -0.65 \pm 0.002$; Shen et al. 2011), our CL quasars span a similar range of black hole masses but exhibit a statistically significant shift toward lower Eddington ratios. The median Eddington ratios for our sample are $\log \lambda_{\text{Edd}} = -1.14 \pm 0.12$ in the bright state and -1.39 ± 0.09 in the dim state. The uncertainties are estimated by bootstrap resampling with 1000 iterations. We employed the Kolmogorov-Smirnov (KS) test to evaluate the differences in Eddington ratio distributions. The test reveals that both the bright-state ($p < 10^{-4}$) and dim-state ($p < 10^{-4}$) CL quasars exhibit significantly different Eddington ratio distributions compared to the typical SDSS quasar population.

When compared with lower-redshift CL quasars, our high-redshift sample exhibits systematically higher Ed-

dington ratios. Local CL quasars typically have $\log \lambda_{\text{Edd}} \sim -2$ (e.g., Wang et al. 2024b; Guo et al. 2025a), significantly lower than our bright-state average of $\log \lambda_{\text{Edd}} \sim -1.14 \pm 0.12$ ($p < 10^{-4}$, KS test). This difference is most likely due to selection bias: at higher redshifts, flux limits preferentially select the most luminous, and thus more highly accreting, CL quasars.

Furthermore, Figure 6 shows the distributions of typical quasars and bright- and dim-state CL quasars in the $L_{\text{bol}}/L_{\text{Edd}}-M_{\text{BH}}$ plane. CL quasars are systematically shifted toward lower accretion rates compared to typical quasars, and the bright-state distribution lies consistently above the dim-state distribution, which is also statistically significant ($p < 10^{-4}$, KS test), reinforcing the idea that the CL phenomenon is closely linked to changes in the accretion rate.

5.3. High-ionization Broad Emission Line Ratio

The C III]/C IV emission-line ratio is widely regarded to be sensitive to the ionization parameter (U), with a larger C III]/C IV typically indicating a lower ionization parameter (e.g., Sethi & Subramanian 2005; Matsuoka et al. 2009). According to the photoionization model (Ferland et al. 1998; Kallman et al. 2004):

$$U = \frac{\int_{\nu_0}^{\infty} L_{\nu} d\nu/h\nu}{4\pi R^2 c n_{\text{H}}}, \quad (6)$$

where R is the distance from the BLRs to the central ionizing source, and n_{H} is the hydrogen density. A larger U indicates the presence of lower-density gas located closer to the central SMBH.

In this work, we find no significant correlation between the C III]/C IV flux ratio and the thermal luminosity, as shown in Figure 7, and the distribution for CL quasars is statistically consistent with that of typical quasars. This indicates that the U does not vary significantly between the bright and dim states, suggesting that the distance between the BLR clouds and the central engine remains largely unchanged during the CL transition.

5.4. Baldwin Effect

The Baldwin effect refers to the phenomenon observed in quasar spectra where the equivalent width (EW) of high-ionization emission lines (C IV) decreases with increasing continuum luminosity, following the relation $L_{\text{con}} \propto 1/\text{EW}$ (Baldwin 1977). However, the underlying physical mechanisms of the Baldwin Effect remain controversial. Several prevailing explanations include: at higher luminosities, the UV-soft X-ray spectrum of the central gravitational source becomes softer, resulting in reduced efficiency for exciting specific emission lines, thereby causing the line intensity to increase less rapidly

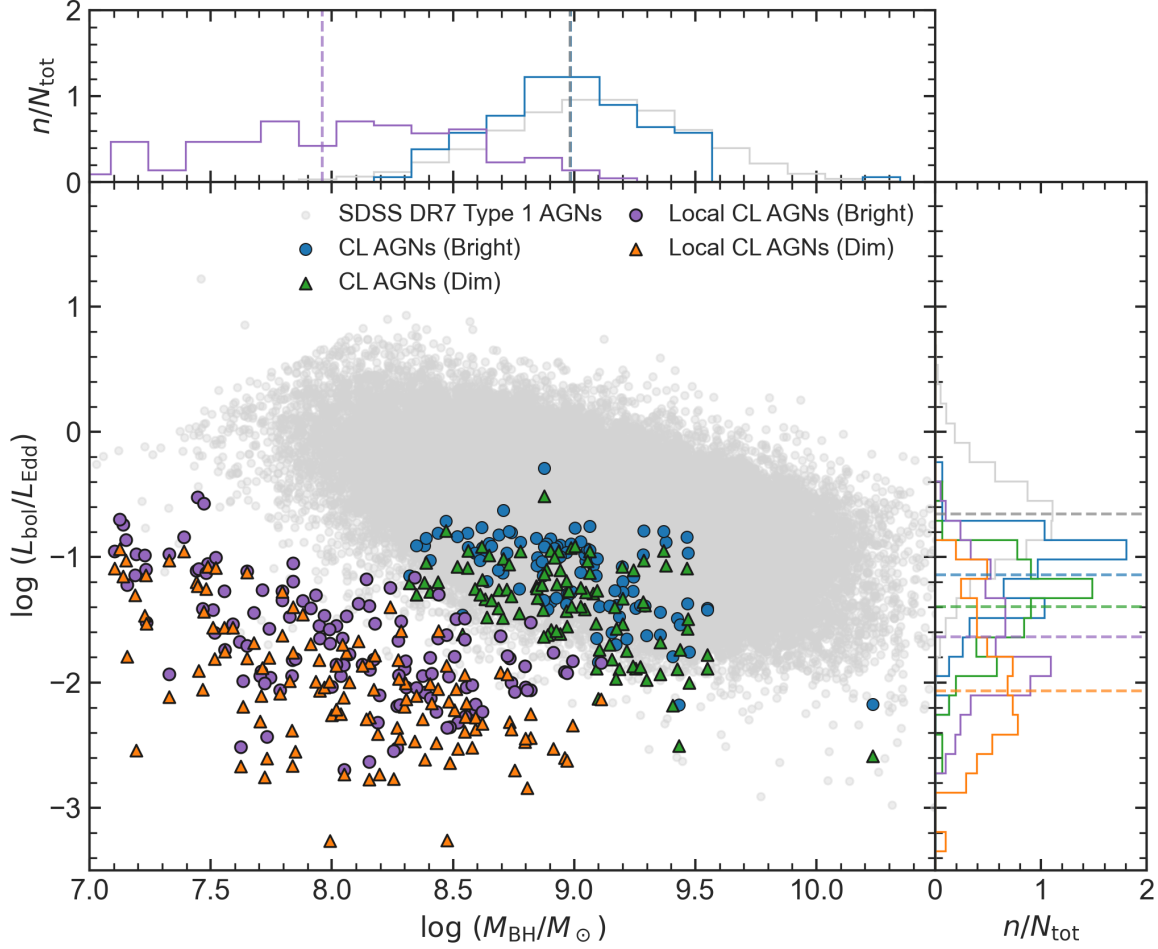


Figure 6. The distribution of CL quasars in this work on the $L_{\text{bol}}/L_{\text{Edd}}-M_{\text{BH}}$ plane is shown alongside a comparison quasar sample (grey circles) from the SDSS DR7 QSO catalog at $z > 0.9$ (Shen et al. 2011). Blue circles and green triangles indicate the bright and dim states, respectively. The purple dots and orange triangles are the local CL quasars ($z < 0.3$) from Guo et al. (2025a) in bright and dim states, respectively. And the dashed lines in the corresponding color represent the linear fitting for the targets in the $L_{\text{bol}}/L_{\text{Edd}}-M_{\text{BH}}$ plane. The top and right subpanels display the distributions of M_{BH} and Eddington ratio, with dashed lines marking their respective average values.

than the continuum luminosity (Baskin & Laor 2004; Wu et al. 2009); Bright AGNs exhibit lower ionization parameters, which similarly lead to relative weakening of line intensity (Mushotzky & Ferland 1984); the time lag of emission-line response leads to a pseudo-Baldwin effect (Pogge & Peterson 1992). Despite the clear Baldwin effect seen in high-ionization lines like C IV, the behavior of lower-ionization lines, such as Mg II, appears to be more complex. Several studies have reported that the equivalent width of Mg II shows a much weaker dependence on continuum luminosity, or even no significant Baldwin effect at all (e.g., Shen et al. 2011; Guo et al. 2019b).

To investigate the Baldwin effect for different BELs, we divide our CL quasars into distinct subsamples based

on the emission-line CL behavior. Figure 8 presents the relationship between the EW and luminosity for several high-ionization emission lines. At the population level, CL quasars follow the Baldwin effect well for both Mg II and C IV lines, with stronger anti-correlations than those observed in the general quasar population, regardless of whether the source is in a bright or dim state. However, the Baldwin effect does not hold for individual CL quasars. We find that the EWs in the bright-state spectra are systematically higher than in the dim-state ones for the same source, which is contrary to the expected Baldwin trend. This apparent contradiction may result from a selection bias: since CL quasars are defined by the appearance or disappearance of BELs, the bright

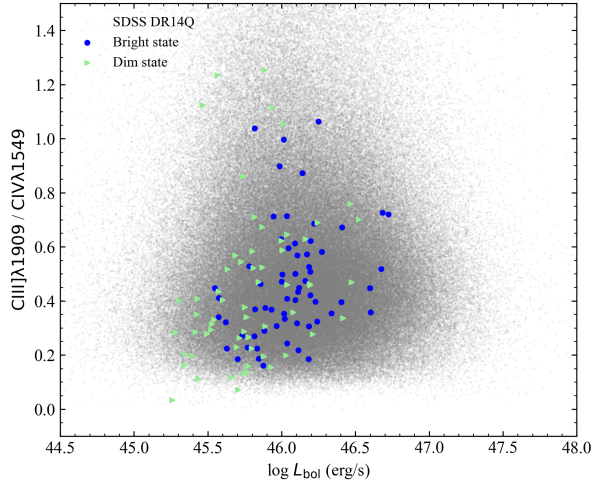


Figure 7. The $\text{C III]}\lambda 1909/\text{C IV}\lambda 1549$ V.S. L_{bol} diagram for the CL quasars in this work with both C III] and C IV emission lines detected. Blue circles and green triangles represent CL quasars in bright and dim states, respectively. Grey dots, shown for comparison, are drawn from the SDSS DR14 QSO catalog (Rakshit et al. 2020).

state is, by definition, more likely to exhibit prominent lines with large EWs.

Notably, the C III] line in the dim state does not exhibit the expected anti-correlation between EW and luminosity. According to the photoionization models of Guo et al. (2020b), the intrinsic line strength of C III] is only about $\sim 10\text{--}15\%$ that of $\text{Ly}\alpha$, resulting in larger measurement uncertainties. Thus, the lack of an observable Baldwin effect for C III] line in the dim state may be due to its inherently low luminosity.

Furthermore, we examine the correlation between the changes in absolute emission line luminosities and changes in continuum luminosity variations for individual CL quasars, as shown in Figure 9. We find a strong positive correlation between the variability of high-ionization lines (e.g., Mg II , C III]) and the change in bolometric luminosity. The slopes are 0.57 and 0.65, with Spearman correlation coefficients r values are 0.83 and 0.64, respectively, and p -values indicating high statistical significance. This result is consistent with a scenario in which the activity of CL quasars is primarily driven by the nuclear region, and the emission-line strength increases with the overall ionizing luminosity, for C IV . Interestingly, the correlation is weaker than for Mg II and C III] (Figure 9). This is plausibly due to its more compact and dynamic region, likely closer to the accretion disk. As such, it may be more susceptible to complex radiative transfer effects, anisotropic illumination, or perturbations from disk winds and outflows (e.g., Richards et al. 2011; Denney 2012). These pro-

cesses can decouple the line response from the overall ionizing continuum, leading to weaker or delayed variability. Exactly, C IV is known to be more blueshifted and asymmetric than other broad lines, further suggesting a non-virialized or wind-dominated origin.

5.5. CL Timescale

The CL timescale refers to the duration over which a Type 1 AGN transforms into a Type 2 AGN (or vice versa), which has later evolved into the timescale for the appearance or disappearance of a particular broad emission line. The observed CL timescale poses a challenge to the typical accretion disk model of AGNs and is crucial to understanding the physical mechanism behind the CL event. Theoretically, the predicted timescale for such transitions is on the order of 10^4 years (Shakura & Sunyaev 1973), which is much longer than the actual observed timescales. However, even the observed CL timescales represent only upper limits, as they depend on the sampling cadence of spectroscopic observations in the bright and dim states. The typical CL timescale is 1-20 years (e.g., Yang et al. 2018; Ricci & Trakhtenbrot 2023). It is noteworthy that some extreme cases exhibit transitions on timescales of just a few months. For instance, the atypical CL AGN 1ES 1927+654 showcased a rapid turn-on over several weeks (Trakhtenbrot et al. 2019), while the CL quasar SDSS J1628+4329 experienced a dramatic dimming and rebrightening within months, potentially driven by variable obscuration (Zelty et al. 2022). Although these specific physical mechanisms may not be representative of the general CL population, they serve to illustrate the observed upper limit of rapid variability that any comprehensive theory must ultimately explain.

In this work, the rest-frame CL timescale for each source is also calculated directly as the time elapsed between the last spectroscopic observation before the transition and the first observation after the transition has occurred. As we lack continuous monitoring, this measured interval represents an upper limit to the true transition timescale. As illustrated in Figure 10, the rest-frame CL timescales span 0.32–6.47 years for turn-on AGNs and 0.82–3.97 years for turn-off AGNs, with one outlier extending to 11.72 years. It is found that there is no significant difference in the timescales between turn-on and turn-off events, with both having an average of around 3 years. However, the CL timescales at high redshift appear to be much shorter than those reported in previous studies, which typically show an average of around 10 years. We note that the spectroscopic cadence of our data, combining the latest DESI DR1 with the long historical baseline of SDSS, is com-

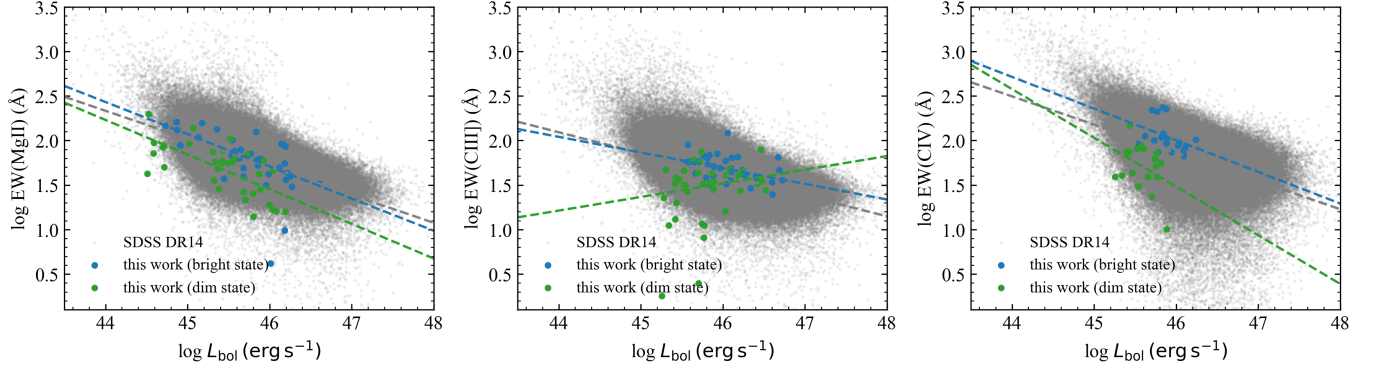


Figure 8. The EW- L_{bol} plane of the CL quasar subsamples in this work. The blue circles and green triangles represent the CL ANGs in the bright states and the dim states, respectively. The grey circles show a comparison quasar sample from the SDSS DR14 QSO catalog (Rakshit et al. 2020). The corresponding color dashed line is the best linear fit for the scatter.

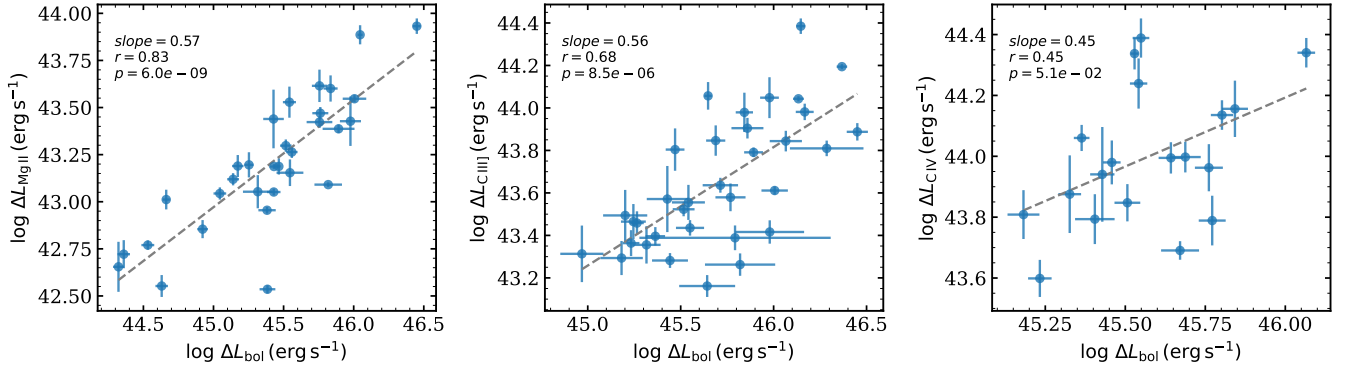


Figure 9. Correlation between the change in BEL luminosity (ΔL_{line}) and the change in bolometric luminosity (ΔL_{bol}) for CL quasars in this work. From left to right, the panels show the results for Mg II, C III], and C IV lines. Each point represents an individual CL quasar with detected line variability. The dashed lines indicate the best-fit linear relations, with the corresponding slope, Spearman correlation coefficient r , and p -value labeled in each panel.

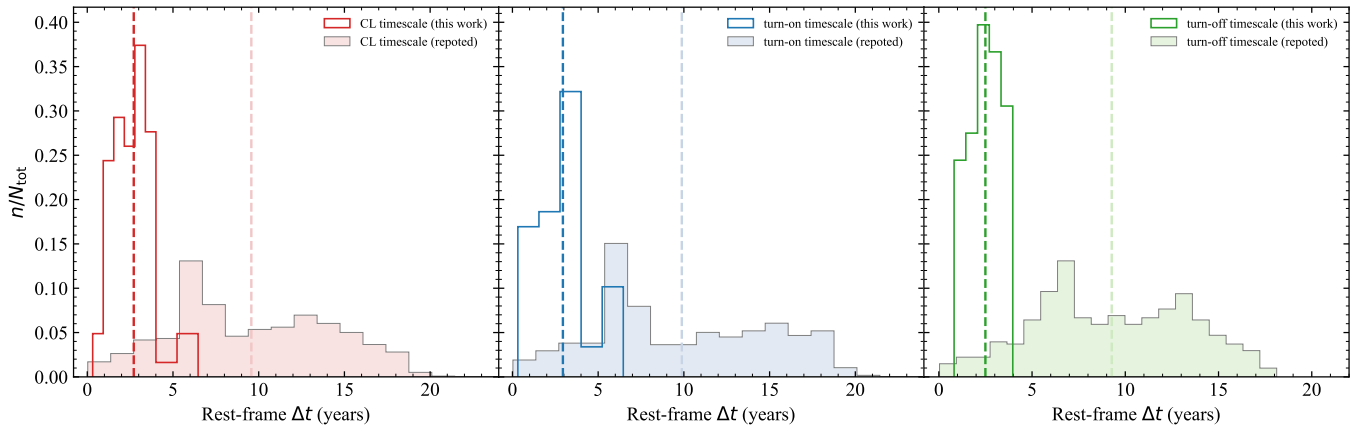


Figure 10. The timescale of the CL phenomenon in this work and reported CL quasars. The left panel is the CL timescale distribution in this work and the previous studies, the middle and the right panels represent the turn-on and turn-off timescale, respectively. The open bars represent the timescale distributions in our sample, and the filled bars correspond to previously reported CL quasars (e.g., Margala et al. 2016; Yang et al. 2018; López-Navas et al. 2023; Wang et al. 2024b; Guo et al. 2024, 2025a). The dashed lines in matching colors indicate the average timescales for each group.

parable to, if not longer than, that of these previous works (e.g., Yang et al. 2018; Wang et al. 2024b; Guo et al. 2024, 2025a). Therefore, the shorter timescales we measure are unlikely to be a cadence artifact. Also, we do not interpret this as an indication of redshift evolution in CL timescales, but rather as a result of selection effects. Firstly, as mentioned earlier, due to instrumental limitations, the measured CL timescales are strongly influenced by observation cadence. The typical time baselines of existing large-scale spectroscopic surveys are around 10–20 years. Secondly, because of redshift effects, the rest-frame CL timescales inferred for low-redshift sources tend to be ~ 10 years, while those at higher redshifts are significantly shorter. Actually, some studies based on light curve analysis suggest that the intrinsic CL timescales may be significantly shorter than the observed ones, possibly even shorter than those estimated in our sample (e.g., Sheng et al. 2017; Wang et al. 2024b). Therefore, more complete datasets and the discovery of CL quasars at even higher redshifts will be crucial to uncover the true nature of CL timescales.

In the preceding subsections, we investigated the Eddington ratio, the Baldwin effect, and the CL timescale of CL quasars. Taken together, these measurements are consistent with a scenario in which CL activity is primarily triggered by variations in the accretion rate. Specifically, the Eddington ratio of CL quasars in the bright state is systematically larger than that in the dim state, providing direct evidence for the role of accretion-rate changes. The Baldwin effect of the high-ionization lines is consistent with the disk-wind scenario (Giustini & Proga 2019), in which changes in the accretion rate may regulate both the ionization state and the dynamical structure of the BLR. Furthermore, our analysis of the CL timescale constrains the transition period to less than ~ 3 years, significantly shorter than the ~ 10 years reported in previous studies. This short timescale cannot be explained by the viscous timescale of a standard disk or obscuration mechanisms, and it places stronger constraints on the accretion-rate variation model.

Taken together, these results outline a coherent picture: CL phenomena are predominantly driven by accretion-rate variations (e.g., disk instability models). When the accretion rate increases, the disk-wind scenario predicts an enhanced supply of BLR material, leading to the emergence of strong BELs. Conversely, when the accretion rate decreases, the BLR gas content diminishes, and BELs weaken or even disappear.

6. SUMMARY

In this study, we conduct a systematic search for high-redshift CL quasars by cross-matching SDSS DR18

and DESI DR1. We identify 97 pairs of high-redshift CL quasars and 135 CL quasar candidates at redshift $z > 0.9$. Among them, 28 cases exhibit CL transitions in Mg II, 59 in C III], 25 in C IV, 26 in Si IV, and 8 in Ly α . The 97 CL quasars comprise 45 turn-on and 52 turn-off events, with a near-equal occurrence ratio. The resulting detection rate of 0.042% is significantly lower than the detection rates found for CL transitions from low ionization emission lines. This discrepancy is primarily attributed to four factors: (1) observational limitations, where high-redshift quasars in dim states may fall below the detection thresholds of current surveys; and (2) the baseline between SDSS and DESI is shorter than the CL timescale; (3) physical constraints, as high-ionization lines generally follow the Baldwin effect well, making it more difficult to identify cases with an inverse Baldwin effect; and (4) the high-redshift quasars activity is at its peak that suppression the state change.

Our sample properties support an accretion-rate-driven origin for the CL phenomenon. They have lower Eddington ratios than typical quasars, averaging $\log \lambda_{\text{Edd}} \sim -1.14$ and -1.39 in the bright and dim states, respectively. This supports the idea that CL behavior preferentially occurs in low accretion states. In addition, we find that high-ionization emission lines in CL quasars still follow the Baldwin effect on a population level, though individual sources can exhibit inverse Baldwin trends. Not only that, our results reveal a strong positive correlation between the changes in bolometric luminosity and the flux variability of high-ionization lines such as Mg II and C III], further supporting that the CL transitions are driven by changes in the accretion rate. Finally, we examine the timescales of CL behavior and find no significant difference between turn-on and turn-off events. The typical timescale of the CL transition is estimated to be around 3 years in the rest frame, which disfavors the obscuration-based scenario. Together, these results indicate changes in the accretion rate.

ACKNOWLEDGEMENTS

We acknowledge the anonymous referee for valuable comments that helped to improve the paper. This work is supported by the National Natural Science Foundation of China (NSFC) under grant No. 12503019 and 12273013. This research is supported by the National Key R&D Program of China with grant No. 2023YFA1608100. This work is also supported by the National Natural Science Foundation of China (NSFC) under grant No. 12273013. The authors also acknowledge support from the National Key R&D Program of China (grant Nos. 2023YFA1607804, 2022YFA1602902,

2023YFA1607800), other NSFC projects (grant Nos. 12120101003, 12373010, 12173051, 12233008, 12403022, and 12103048), and the China Manned Space Project (No. CMS-CSST-2025-A06). The authors also acknowledge the Strategic Priority Research Program of the Chinese Academy of Sciences with grant Nos. XDB0550100 and XDB0550000.

We acknowledge the use of DESI data. DESI is a scientific collaboration managed by the U.S. Department of Energy’s Lawrence Berkeley National Laboratory, with primary funding provided by the U.S. Department of Energy Office of Science and the National Science Foundation. Additional support is acknowledged from international collaborating institutions and participating universities. This work also utilizes data from the SDSS. Funding for SDSS-V has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy Office of Science.

We acknowledge the efforts for public data from CTRS, PS1, and ZTF. The Catalina Sky Survey is funded by the National Aeronautics and Space Administration under grant No. NNG05GF22G, issued through the Science Mission Directorate Near-Earth Objects Observations Program. The CRTS survey is supported by the US National Science Foundation under grants AST-0909182 and AST-1313422. The CRTS survey is supported by the US National Science Foundation under grants AST-0909182 and AST-1313422. PS1 has

been made possible through contributions by the Institute for Astronomy, the University of Hawaii, the Pan-STARRS Project Office, the Max-Planck Society, and its participating institutes, the Max Planck Institute for Astronomy, Heidelberg and the Max Planck Institute for Extraterrestrial Physics, Garching, The Johns Hopkins University, Durham University, the University of Edinburgh, Queen’s University of Belfast, the Harvard-Smithsonian Center for Astrophysics, the Las Cumbres Observatory Global Telescope Network Incorporated, the National Central University of Taiwan, the Space Telescope Science Institute, the National Aeronautics and Space Administration under grant No. NNX08AR22G issued through the Planetary Science Division of the NASA Science Mission Directorate, the National Science Foundation under grant No. AST-1238877, the University of Maryland, and Eotvos Lorand University (ELTE). ZTF is supported by the National Science Foundation under grant No. AST-2034437 and a collaboration including Caltech, IPAC, the Weizmann Institute for Science, the Oskar Klein Center at Stockholm University, the University of Maryland, Deutsches Elektronen-Synchrotron and Humboldt University, the TANGO Consortium of Taiwan, the University of Wisconsin at Milwaukee, Trinity College Dublin, Lawrence Livermore National Laboratories, and IN2P3, France. Operations are conducted by COO, IPAC, and UW.

REFERENCES

- Abazajian, K., Adelman-McCarthy, J. K., Agüeros, M. A., et al. 2004, *AJ*, 128, 502, doi: [10.1086/421365](https://doi.org/10.1086/421365)
- Abazajian, K. N., Adelman-McCarthy, J. K., Agüeros, M. A., et al. 2009, *ApJS*, 182, 543, doi: [10.1088/0067-0049/182/2/543](https://doi.org/10.1088/0067-0049/182/2/543)
- Almeida, A., Anderson, S. F., Argudo-Fernández, M., et al. 2023, *ApJS*, 267, 44, doi: [10.3847/1538-4365/acda98](https://doi.org/10.3847/1538-4365/acda98)
- Antonucci, R. 1993, *ARA&A*, 31, 473, doi: [10.1146/annurev.aa.31.090193.002353](https://doi.org/10.1146/annurev.aa.31.090193.002353)
- Aromal, P., Srianand, R., & Petitjean, P. 2022, *MNRAS*, 514, 1975, doi: [10.1093/mnras/stac1460](https://doi.org/10.1093/mnras/stac1460)
- Baldwin, J. A. 1977, *ApJ*, 214, 679, doi: [10.1086/155294](https://doi.org/10.1086/155294)
- Baskin, A., & Laor, A. 2004, *MNRAS*, 350, L31, doi: [10.1111/j.1365-2966.2004.07833.x](https://doi.org/10.1111/j.1365-2966.2004.07833.x)
- Becker, R. H., White, R. L., & Helfand, D. J. 1995, *ApJ*, 450, 559, doi: [10.1086/176166](https://doi.org/10.1086/176166)
- Bellm, E. C., Kulkarni, S. R., Graham, M. J., et al. 2019, *PASP*, 131, 018002, doi: [10.1088/1538-3873/aaecbe](https://doi.org/10.1088/1538-3873/aaecbe)
- Bennert, N., Falcke, H., Schulz, H., Wilson, A. S., & Wills, B. J. 2002, *ApJL*, 574, L105, doi: [10.1086/342420](https://doi.org/10.1086/342420)
- Blanchard, P. K., Nicholl, M., Berger, E., et al. 2017, *ApJ*, 843, 106, doi: [10.3847/1538-4357/aa77f7](https://doi.org/10.3847/1538-4357/aa77f7)
- Bolton, A. S., Schlegel, D. J., Aubourg, É., et al. 2012, *AJ*, 144, 144, doi: [10.1088/0004-6256/144/5/144](https://doi.org/10.1088/0004-6256/144/5/144)
- Capellupo, D. M., Hamann, F., Shields, J. C., Rodríguez Hidalgo, P., & Barlow, T. A. 2011, *MNRAS*, 413, 908, doi: [10.1111/j.1365-2966.2010.18185.x](https://doi.org/10.1111/j.1365-2966.2010.18185.x)
- Chambers, K. C., Magnier, E. A., Metcalfe, N., et al. 2016, *arXiv e-prints*, arXiv:1612.05560, doi: [10.48550/arXiv.1612.05560](https://doi.org/10.48550/arXiv.1612.05560)
- Chen, Z.-Q., Guo, W.-J., Zou, H., Liu, M.-F., & Yuan, Q.-R. 2025, *Research in Astronomy and Astrophysics*, 25, 095012, doi: [10.1088/1674-4527/ade952](https://doi.org/10.1088/1674-4527/ade952)
- Clavel, J., Reichert, G. A., Alloin, D., et al. 1991, *ApJ*, 366, 64, doi: [10.1086/169540](https://doi.org/10.1086/169540)
- Dempsey, R., & Zakamska, N. L. 2018, *MNRAS*, 477, 4615, doi: [10.1093/mnras/sty941](https://doi.org/10.1093/mnras/sty941)

- Denney, K. D. 2012, *ApJ*, 759, 44,
doi: [10.1088/0004-637X/759/1/44](https://doi.org/10.1088/0004-637X/759/1/44)
- DESI Collaboration, Aghamousa, A., Aguilar, J., et al. 2016a, arXiv e-prints, arXiv:1611.00036,
doi: [10.48550/arXiv.1611.00036](https://doi.org/10.48550/arXiv.1611.00036)
- . 2016b, arXiv e-prints, arXiv:1611.00037,
doi: [10.48550/arXiv.1611.00037](https://doi.org/10.48550/arXiv.1611.00037)
- DESI Collaboration, Abareshi, B., Aguilar, J., et al. 2022, *AJ*, 164, 207, doi: [10.3847/1538-3881/ac882b](https://doi.org/10.3847/1538-3881/ac882b)
- DESI Collaboration, Adame, A. G., Aguilar, J., et al. 2024a, *AJ*, 167, 62, doi: [10.3847/1538-3881/ad0b08](https://doi.org/10.3847/1538-3881/ad0b08)
- . 2024b, *AJ*, 168, 58, doi: [10.3847/1538-3881/ad3217](https://doi.org/10.3847/1538-3881/ad3217)
- Dong, Q., Zhang, Z.-X., Gu, W.-M., Sun, M., & Zheng, Y.-G. 2024, arXiv e-prints, arXiv:2408.07335,
doi: [10.48550/arXiv.2408.07335](https://doi.org/10.48550/arXiv.2408.07335)
- Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2009, *ApJ*, 696, 870, doi: [10.1088/0004-637X/696/1/870](https://doi.org/10.1088/0004-637X/696/1/870)
- Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2012, in *IAU Symposium*, Vol. 285, *New Horizons in Time Domain Astronomy*, ed. E. Griffin, R. Hanisch, & R. Seaman, 306–308, doi: [10.1017/S1743921312000889](https://doi.org/10.1017/S1743921312000889)
- Eisenstein, D. J., Weinberg, D. H., Agol, E., et al. 2011, *AJ*, 142, 72, doi: [10.1088/0004-6256/142/3/72](https://doi.org/10.1088/0004-6256/142/3/72)
- Ferland, G. J., Korista, K. T., Verner, D. A., et al. 1998, *PASP*, 110, 761, doi: [10.1086/316190](https://doi.org/10.1086/316190)
- Filiz Ak, N., Brandt, W. N., Hall, P. B., et al. 2013, *ApJ*, 777, 168, doi: [10.1088/0004-637X/777/2/168](https://doi.org/10.1088/0004-637X/777/2/168)
- Fitzpatrick, E. L. 1999, *PASP*, 111, 63, doi: [10.1086/316293](https://doi.org/10.1086/316293)
- Giustini, M., & Proga, D. 2019, *A&A*, 630, A94,
doi: [10.1051/0004-6361/201833810](https://doi.org/10.1051/0004-6361/201833810)
- Goad, M. R., Korista, K. T., De Rosa, G., et al. 2016, *ApJ*, 824, 11, doi: [10.3847/0004-637X/824/1/11](https://doi.org/10.3847/0004-637X/824/1/11)
- Green, P. J., Pulgarin-Duque, L., Anderson, S. F., et al. 2022, *ApJ*, 933, 180, doi: [10.3847/1538-4357/ac743f](https://doi.org/10.3847/1538-4357/ac743f)
- Gunn, J. E., Siegmund, W. A., Mannery, E. J., et al. 2006, *AJ*, 131, 2332, doi: [10.1086/500975](https://doi.org/10.1086/500975)
- Guo, H., Liu, X., Shen, Y., et al. 2019a, *MNRAS*, 482, 3288, doi: [10.1093/mnras/sty2920](https://doi.org/10.1093/mnras/sty2920)
- Guo, H., Sun, M., Liu, X., et al. 2019b, *ApJL*, 883, L44,
doi: [10.3847/2041-8213/ab4138](https://doi.org/10.3847/2041-8213/ab4138)
- Guo, H., Peng, J., Zhang, K., et al. 2020a, *ApJ*, 905, 52,
doi: [10.3847/1538-4357/abc2ce](https://doi.org/10.3847/1538-4357/abc2ce)
- Guo, H., Shen, Y., He, Z., et al. 2020b, *ApJ*, 888, 58,
doi: [10.3847/1538-4357/ab5db0](https://doi.org/10.3847/1538-4357/ab5db0)
- Guo, W.-J., Zou, H., Fawcett, V. A., et al. 2024, *ApJS*, 270, 26, doi: [10.3847/1538-4365/ad118a](https://doi.org/10.3847/1538-4365/ad118a)
- Guo, W.-J., Zou, H., Greenwell, C. L., et al. 2025a, *ApJS*, 278, 28, doi: [10.3847/1538-4365/adc124](https://doi.org/10.3847/1538-4365/adc124)
- Guo, W.-J., Pan, Z., Siudek, M., et al. 2025b, *ApJL*, 981, L8, doi: [10.3847/2041-8213/adb426](https://doi.org/10.3847/2041-8213/adb426)
- Guy, J., Bailey, S., Kremin, A., et al. 2023, *AJ*, 165, 144,
doi: [10.3847/1538-3881/acb212](https://doi.org/10.3847/1538-3881/acb212)
- Helfand, D. J., White, R. L., & Becker, R. H. 2015, *ApJ*, 801, 26, doi: [10.1088/0004-637X/801/1/26](https://doi.org/10.1088/0004-637X/801/1/26)
- Ho, L. C. 2008, *ARA&A*, 46, 475,
doi: [10.1146/annurev.astro.45.051806.110546](https://doi.org/10.1146/annurev.astro.45.051806.110546)
- Hutchinson, T. A., Bolton, A. S., Dawson, K. S., et al. 2016, *AJ*, 152, 205, doi: [10.3847/0004-6256/152/6/205](https://doi.org/10.3847/0004-6256/152/6/205)
- Hutsemékers, D., Agís González, B., Marin, F., et al. 2019, *A&A*, 625, A54, doi: [10.1051/0004-6361/201834633](https://doi.org/10.1051/0004-6361/201834633)
- Jin, J.-J., Wu, X.-B., & Feng, X.-T. 2022, *ApJ*, 926, 184,
doi: [10.3847/1538-4357/ac410c](https://doi.org/10.3847/1538-4357/ac410c)
- Kallman, T. R., Palmeri, P., Bautista, M. A., Mendoza, C., & Krolik, J. H. 2004, *ApJS*, 155, 675, doi: [10.1086/424039](https://doi.org/10.1086/424039)
- LaMassa, S. M., Cales, S., Moran, E. C., et al. 2015, *ApJ*, 800, 144, doi: [10.1088/0004-637X/800/2/144](https://doi.org/10.1088/0004-637X/800/2/144)
- Levi, M., Bebek, C., Beers, T., et al. 2013, arXiv e-prints, arXiv:1308.0847, doi: [10.48550/arXiv.1308.0847](https://doi.org/10.48550/arXiv.1308.0847)
- Li, R., Ho, L. C., Ricci, C., et al. 2022, *ApJ*, 933, 70,
doi: [10.3847/1538-4357/ac714a](https://doi.org/10.3847/1538-4357/ac714a)
- López-Navas, E., Sánchez-Sáez, P., Arévalo, P., et al. 2023, *MNRAS*, 524, 188, doi: [10.1093/mnras/stad1893](https://doi.org/10.1093/mnras/stad1893)
- MacLeod, C. L., Ross, N. P., Lawrence, A., et al. 2016, *MNRAS*, 457, 389, doi: [10.1093/mnras/stv2997](https://doi.org/10.1093/mnras/stv2997)
- MacLeod, C. L., Green, P. J., Anderson, S. F., et al. 2019, *ApJ*, 874, 8, doi: [10.3847/1538-4357/ab05e2](https://doi.org/10.3847/1538-4357/ab05e2)
- Margala, D., Kirkby, D., Dawson, K., et al. 2016, *ApJ*, 831, 157, doi: [10.3847/0004-637X/831/2/157](https://doi.org/10.3847/0004-637X/831/2/157)
- Masci, F. J., Laher, R. R., Rusholme, B., et al. 2019, *PASP*, 131, 018003, doi: [10.1088/1538-3873/aae8ac](https://doi.org/10.1088/1538-3873/aae8ac)
- Matsuoka, K., Nagao, T., Maiolino, R., Marconi, A., & Taniguchi, Y. 2009, *A&A*, 503, 721,
doi: [10.1051/0004-6361/200811478](https://doi.org/10.1051/0004-6361/200811478)
- Matthews, J. H., Knigge, C., Higginbottom, N., et al. 2020, *MNRAS*, 492, 5540, doi: [10.1093/mnras/staa136](https://doi.org/10.1093/mnras/staa136)
- Merloni, A., Dwelly, T., Salvato, M., et al. 2015, *MNRAS*, 452, 69, doi: [10.1093/mnras/stv1095](https://doi.org/10.1093/mnras/stv1095)
- Miller, T. N., Doel, P., Gutierrez, G., et al. 2024, *AJ*, 168, 95, doi: [10.3847/1538-3881/ad45fe](https://doi.org/10.3847/1538-3881/ad45fe)
- Mushotzky, R., & Ferland, G. J. 1984, *ApJ*, 278, 558,
doi: [10.1086/161822](https://doi.org/10.1086/161822)
- Netzer, H. 2013, *The Physics and Evolution of Active Galactic Nuclei*
- Panda, S., & Śniegowska, M. 2024, *ApJS*, 272, 13,
doi: [10.3847/1538-4365/ad344f](https://doi.org/10.3847/1538-4365/ad344f)
- Perez, E., Robinson, A., & de La Fuente, L. 1992, *MNRAS*, 255, 502, doi: [10.1093/mnras/255.3.502](https://doi.org/10.1093/mnras/255.3.502)
- Pogge, R. W., & Peterson, B. M. 1992, *AJ*, 103, 1084,
doi: [10.1086/116127](https://doi.org/10.1086/116127)

- Rakshit, S., Stalin, C. S., & Kotilainen, J. 2020, *ApJS*, 249, 17, doi: [10.3847/1538-4365/ab99c5](https://doi.org/10.3847/1538-4365/ab99c5)
- Ren, W., Guo, H., Shen, Y., et al. 2024a, arXiv e-prints, arXiv:2406.17598, doi: [10.48550/arXiv.2406.17598](https://doi.org/10.48550/arXiv.2406.17598)
- Ren, W., Wang, J., Cai, Z., & Hu, X. 2024b, *ApJ*, 963, 7, doi: [10.3847/1538-4357/ad17cb](https://doi.org/10.3847/1538-4357/ad17cb)
- Ricci, C., & Trakhtenbrot, B. 2023, *Nature Astronomy*, 7, 1282, doi: [10.1038/s41550-023-02108-4](https://doi.org/10.1038/s41550-023-02108-4)
- Richards, G. T., Lacy, M., Storrie-Lombardi, L. J., et al. 2006, *ApJS*, 166, 470, doi: [10.1086/506525](https://doi.org/10.1086/506525)
- Richards, G. T., Kruczek, N. E., Gallagher, S. C., et al. 2011, *AJ*, 141, 167, doi: [10.1088/0004-6256/141/5/167](https://doi.org/10.1088/0004-6256/141/5/167)
- Ross, N. P., Graham, M. J., Calderone, G., et al. 2020, *MNRAS*, 498, 2339, doi: [10.1093/mnras/staa2415](https://doi.org/10.1093/mnras/staa2415)
- Ruan, J. J., Anderson, S. F., Cales, S. L., et al. 2016, *ApJ*, 826, 188, doi: [10.3847/0004-637X/826/2/188](https://doi.org/10.3847/0004-637X/826/2/188)
- Schlafly, E. F., Kirkby, D., Schlegel, D. J., et al. 2023, *AJ*, 166, 259, doi: [10.3847/1538-3881/ad0832](https://doi.org/10.3847/1538-3881/ad0832)
- Sethi, S. K., & Subramanian, K. 2005, *MNRAS*, 356, 778, doi: [10.1111/j.1365-2966.2004.08520.x](https://doi.org/10.1111/j.1365-2966.2004.08520.x)
- Shakura, N. I., & Sunyaev, R. A. 1973, *A&A*, 24, 337
- Shen, Y., Richards, G. T., Strauss, M. A., et al. 2011, *ApJS*, 194, 45, doi: [10.1088/0067-0049/194/2/45](https://doi.org/10.1088/0067-0049/194/2/45)
- Shen, Y., Brandt, W. N., Dawson, K. S., et al. 2015, *ApJS*, 216, 4, doi: [10.1088/0067-0049/216/1/4](https://doi.org/10.1088/0067-0049/216/1/4)
- Shen, Y., Hall, P. B., Horne, K., et al. 2019, *ApJS*, 241, 34, doi: [10.3847/1538-4365/ab074f](https://doi.org/10.3847/1538-4365/ab074f)
- Sheng, Z., Wang, T., Jiang, N., et al. 2017, *ApJL*, 846, L7, doi: [10.3847/2041-8213/aa85de](https://doi.org/10.3847/2041-8213/aa85de)
- . 2020, *ApJ*, 889, 46, doi: [10.3847/1538-4357/ab5af9](https://doi.org/10.3847/1538-4357/ab5af9)
- Silber, J. H., Fagrelus, P., Fanning, K., et al. 2023, *AJ*, 165, 9, doi: [10.3847/1538-3881/ac9ab1](https://doi.org/10.3847/1538-3881/ac9ab1)
- Smee, S. A., Gunn, J. E., Uomoto, A., et al. 2013, *AJ*, 146, 32, doi: [10.1088/0004-6256/146/2/32](https://doi.org/10.1088/0004-6256/146/2/32)
- Sniegowska, M., Czerny, B., Bon, E., & Bon, N. 2020, *A&A*, 641, A167, doi: [10.1051/0004-6361/202038575](https://doi.org/10.1051/0004-6361/202038575)
- Spergel, D. N., Verde, L., Peiris, H. V., et al. 2003, *ApJS*, 148, 175, doi: [10.1086/377226](https://doi.org/10.1086/377226)
- Sun, M., Trump, J. R., Shen, Y., et al. 2015, *ApJ*, 811, 42, doi: [10.1088/0004-637X/811/1/42](https://doi.org/10.1088/0004-637X/811/1/42)
- Tonry, J. L., Stubbs, C. W., Lykke, K. R., et al. 2012, *ApJ*, 750, 99, doi: [10.1088/0004-637X/750/2/99](https://doi.org/10.1088/0004-637X/750/2/99)
- Trakhtenbrot, B., Arcavi, I., MacLeod, C. L., et al. 2019, *ApJ*, 883, 94, doi: [10.3847/1538-4357/ab39e4](https://doi.org/10.3847/1538-4357/ab39e4)
- Trump, J. R., Impey, C. D., Kelly, B. C., et al. 2011, *ApJ*, 733, 60, doi: [10.1088/0004-637X/733/1/60](https://doi.org/10.1088/0004-637X/733/1/60)
- Urry, C. M., & Padovani, P. 1995, *PASP*, 107, 803, doi: [10.1086/133630](https://doi.org/10.1086/133630)
- Vestergaard, M., & Peterson, B. M. 2006, *ApJ*, 641, 689, doi: [10.1086/500572](https://doi.org/10.1086/500572)
- Wang, S., Woo, J.-H., Gallo, E., et al. 2024a, arXiv e-prints, arXiv:2410.15587, doi: [10.48550/arXiv.2410.15587](https://doi.org/10.48550/arXiv.2410.15587)
- . 2024b, *ApJ*, 966, 128, doi: [10.3847/1538-4357/ad3049](https://doi.org/10.3847/1538-4357/ad3049)
- Wolfe, A. M., Turnshek, D. A., Smith, H. E., & Cohen, R. D. 1986, *ApJS*, 61, 249, doi: [10.1086/191114](https://doi.org/10.1086/191114)
- Wu, J., Vanden Berk, D. E., Brandt, W. N., et al. 2009, *ApJ*, 702, 767, doi: [10.1088/0004-637X/702/1/767](https://doi.org/10.1088/0004-637X/702/1/767)
- Yang, Q., Green, P. J., Wu, X.-B., et al. 2025, *ApJ*, 980, 91, doi: [10.3847/1538-4357/ad94ed](https://doi.org/10.3847/1538-4357/ad94ed)
- Yang, Q., Wu, X.-B., Fan, X., et al. 2018, *ApJ*, 862, 109, doi: [10.3847/1538-4357/aaca3a](https://doi.org/10.3847/1538-4357/aaca3a)
- Yang, Q., Green, P. J., MacLeod, C. L., et al. 2023, *ApJ*, 953, 61, doi: [10.3847/1538-4357/acdedd](https://doi.org/10.3847/1538-4357/acdedd)
- Zeltyn, G., Trakhtenbrot, B., Eracleous, M., et al. 2022, *ApJL*, 939, L16, doi: [10.3847/2041-8213/ac9a47](https://doi.org/10.3847/2041-8213/ac9a47)
- . 2024, *ApJ*, 966, 85, doi: [10.3847/1538-4357/ad2f30](https://doi.org/10.3847/1538-4357/ad2f30)
- Zhu, L.-T., Li, J., Wang, Z., & Zhang, J.-J. 2024, *MNRAS*, 530, 3538, doi: [10.1093/mnras/stae1044](https://doi.org/10.1093/mnras/stae1044)

APPENDIX

A. FIBER-DROP CASE

Fiber drop refers to the failure to obtain a valid spectrum due to issues such as fiber misalignment, fiber collision, or mechanical malfunction, resulting in problematic or unusable flux data (Shen et al. 2015; Sun et al. 2015; Guo et al. 2020b). This phenomenon becomes more prominent at higher redshifts, where targets are typically fainter and more susceptible to observational limitations. For studies aiming to identify CL quasars, a rare class of quasars exhibiting dramatic variability in emission line fluxes on timescales of months to years, fiber drop poses a significant challenge, as it can mimic or obscure the spectral transitions that are critical for CL quasar classification. As shown in Figure 11, the spectra from SDSS and DESI exhibit a striking discrepancy in flux levels. In the SDSS spectrum, the Mg II, C III], and Si IV emission lines are nearly buried in noise, while in the DESI spectrum, these lines are clearly visible, so much so that the object was initially misidentified as a CL quasar. However, we found that the pseudo-magnitude derived from the SDSS spectrum is significantly fainter than the contemporaneous PS1 photometry. After the SDSS flux was adjusted to match the actual photometric brightness, the spectral difference between SDSS and DESI largely disappeared. Identifying and removing such false CL quasar candidates caused by fiber drop is, therefore, a necessary and critical step in our analysis.

B. HIGH-REDSHIFT CL QUASAR CANDIDATE CATALOG

Table 6. CL quasar candidates identified in this work

SDSS_NAME	R.A.	Dec.	Redshift	MJD_SDSS	MJD_DESI	Transition
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J000908.69+303733.6	2.2862	30.626	2.3471	56566	59475.43985	on
J002245.89+061729.0	5.6912	6.2914	1.4869	58396	59525.21465	on
J002829.91-005055.4	7.1246	-0.8487	2.361	55447	59492.30014	off
J003111.32-001121.2	7.7972	-0.1892	1.5139	58045	59494.29318	on
J003646.67+070100.0	9.1944	7.0167	1.5224	58398	59498.29944	on
J003827.88+314744.2	9.6162	31.7956	1.7597	57364	59531.15362	off
J004108.69+223401.7	10.2862	22.5672	1.0473	56949	59554.14933	on
J004537.42+061652.6	11.4059	6.2813	2.465	55888	59532.54183	on
J004830.19+010622.6	12.1258	1.1063	1.6745	57278	59484.34243	off
J010345.18-000711.7	15.9382	-0.1199	2.3171	55475	59493.08173	on

NOTE—The table is in its entirety in the machine-readable format.

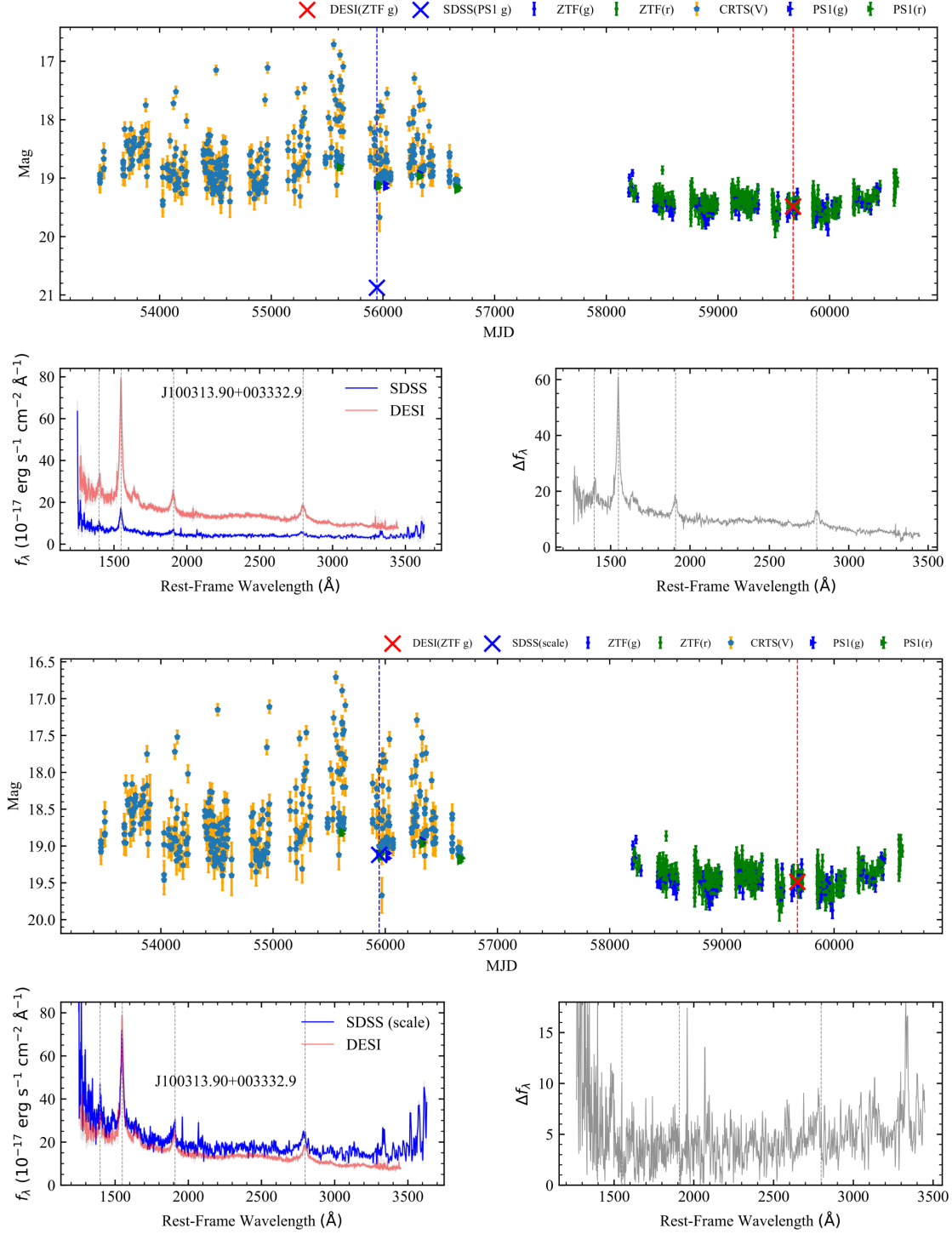


Figure 11. An example of a false CL quasar caused by fiber drop issues. The top panel shows the nearly 20-year light curve compiled from CRTS V-band (dark blue pentagons), PS1 *g*-band (blue triangles), *r*-band (green triangles), ZTF *g*-band (blue circles), and *r*-band (green circles). The blue and red dashed vertical lines indicate the epochs of SDSS and DESI spectroscopic observations, respectively. The corresponding “X” markers represent the pseudo-magnitudes derived by convolving the spectra with filter response curves. The lower-left panel displays the original spectra from SDSS (blue) and DESI (red). The lower-right panel on the left side shows the difference in flux between the two spectra. The bottom panels are identical in layout, except that the SDSS pseudo magnitudes and spectra have been flux-scaled to match the actual photometric level (PS1 *g*-band).