



Searching for Changing-look AGN Candidates through Optical and Mid-infrared Variability

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Abstract

Changing-look (CL) active galactic nuclei (AGNs) are an extremely rare type of AGNs, characterized by the appearance (turn-on) or disappearance (turn-off) of broad emission lines within months to years. We construct a sample of 211 CL AGN candidates by systematically searching the Sloan Digital Sky Survey spectra classified as GALAXY, but with the Zwicky Transient Facility and Near-Earth Object Wide-Field Infrared Explorer mid-infrared light curves showing significant variability, at the redshift range from 0.1 to 0.75. To examine the success rate of this method, we cross-match the candidate sample with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope and the Dark Energy Spectroscopic Instrument for repeat spectra, finding that the success rate of this method is 50%. By incorporating previously reported CL AGNs, a total of 48 CL AGNs have been identified within our sample, including two recurrent CL AGNs newly confirmed in this work. Our results suggest that the typical rest-frame timescale of CL behavior is from 1.7 to 18.1 yr, which is inconsistent with the obscuration model, and the Eddington ratios of CL AGNs are about 0.01 in the bright state. Additionally, our CL AGN sample follows the $M_{\text{BH}}-\sigma_*$ relation of quiescent galaxies. In the future, we expect to detect more galaxies turning into Type 1 AGNs in this CL AGN candidate sample.

Key words: accretion, accretion disks – galaxies: active – galaxies: nuclei – (galaxies:) quasars: emission lines – catalogs

1. Introduction

Active galactic nuclei (AGNs) are among the most energetic objects in the universe. Observationally, AGNs are classified into Type 1 and Type 2 based on their emission-line spectra (Seyfert 1943). Type 1 AGNs exhibit both broad and narrow emission lines, whereas Type 2 AGNs show only narrow lines (Netzer 2015). The AGN unification model (UM) explains this dichotomy by invoking an anisotropic structure, which includes a supermassive black hole (SMBH), an accretion disk, a broad-line region (BLR), a dusty torus, and a narrow-line region (NLR), with some AGNs additionally hosting relativistic jets (Antonucci 1993; Urry & Padovani 1995). In Type 1 AGNs, the observer’s line of sight has a low inclination angle relative to the torus axis, allowing direct view of both the unobscured BLR and the NLR. In Type 2 AGNs, the torus obscures the BLR along high-inclination sightlines, leaving only the NLR visible (Ramos Almeida & Ricci 2017). AGNs can be further subdivided into intermediate types (e.g., Type 1.5, 1.8, and 1.9) based on the relative strength of the broad and narrow components of the Balmer emission lines, especially $H\beta$ (Osterbrock 1981). This classification typically relies on the flux ratio of the broad to narrow $H\beta$ component: Type 1.5 AGNs show a broad $H\beta$ component with a flux comparable to or slightly stronger than the narrow component

(flux ratio > 0.5), Type 1.8 AGNs exhibit a weak broad $H\beta$ (flux ratio < 0.3), while in Type 1.9 AGNs, the broad $H\beta$ is undetectable, and only a weak broad $H\alpha$ component is observed.

In the past few decades, the discovery of AGNs that transition between Type 1 and Type 2 within months to years, the so-called “changing-look” (CL) AGNs, have posed a serious challenge to the standard accretion disk theory, as the observed timescales are orders of magnitude shorter than the expected viscous timescale (Shakura & Sunyaev 1973). These rapid transitions also raise questions about the simplicity of the AGN UM. One of the first CL phenomena was discovered by Tohline & Osterbrock (1976) in NGC 7603, where the $H\beta$ line decreased by a factor of 3 within a year. This timescale inspires a deeper understanding of the internal structure of the AGN.

Currently, some of the main hypotheses that could potentially explain the CL phenomenon include: (1) the movement of a fractured dusty torus or cloud structures, or accelerating outflows (e.g., Nenkova et al. 2008a, 2008b; Elitzur 2012; Ricci & Trakhtenbrot 2023); however, this scenario has been strongly disfavored by mid-infrared (MIR) variability studies, which indicate that the observed transitions are more consistent with intrinsic changes in the accretion rate (e.g., Sheng et al. 2017); (2) tidal disruption event (TDE) that occurs when a star

moves within the tidal disruption radius of an SMBH, causing the star to be torn apart by the SMBH, which can lead to a change in types (e.g., Merloni et al. 2015; Blanchard et al. 2017; Li et al. 2022); (3) instabilities in the accretion disk may lead to changes in the accretion rate, which in turn drive the evolution of the BLR (e.g., Esin et al. 1997; Elitzur & Ho 2009; Dexter & Agol 2011; Elitzur et al. 2014; Ramos Almeida & Ricci 2017; MacLeod et al. 2019; Wang et al. 2024a). However, the underlying physical mechanism behind the CL occurrence is still uncertain. Therefore, a larger CL AGN sample could help in exploring the underlying causes more thoroughly.

CL AGNs could be identified by optical variability. Since the central engine is obscured by the dusty torus in Type 2 AGN, its optical variability is notably weaker compared to that in Type 1 AGN (Yip et al. 2009; Sánchez et al. 2017). López-Navas et al. (2023a) proposed a method to distinguish between Type 1 and Type 2 AGNs based on optical variability. Therefore, for a spectrum at a given moment appearing as a quiescent galaxy or Type 2 AGN, which means it lacks broad lines or has very weak broad components, if its long-term light curve shows significant variability characteristic of a Type 1 AGN, then it is likely a CL AGN. López-Navas et al. (2022) discovered six CL AGNs and 60 candidates through optical variability. Subsequently, follow-up spectroscopy was conducted on 30 of these candidates, revealing that 50% of them were indeed CL AGNs (López-Navas et al. 2023b). Similarly, Wang et al. (2024b) identified 35 turn-on and 12 turn-off CL candidates using optical variability. Follow-up spectroscopy of 21 turn-on and five turn-off candidates confirmed 17 and four CL AGNs, respectively, achieving a success rate of 80%. This indicates that searching for CL behavior through variability is a feasible and efficient method.

In addition to optical variability, MIR variability is also a significant feature of AGNs. According to the UM, the dusty torus is considered to be a “doughnut-like” structure located between the BLR and NLR (Tadhunter 2008). Some photons emitted by the accretion disk are absorbed or reprocessed by the dust torus, emitting MIR photons; the variation of the MIR light curve can be used to indicate the activity of the central engine (Sheng et al. 2017). Previous works suggest that the MIR color ($W1 - W2$) of galaxies is less than 0.5, but the AGN-like MIR color is larger than 0.8 (Yan et al. 2013). Therefore, if a galaxy transitions into an AGN (turns on), the MIR color will become redder accordingly, and the MIR brightness will also increase. This method can also be used to search for CL AGN candidates (Ross et al. 2018; Stern et al. 2018; Sheng et al. 2020).

To improve the success rate of searching CL AGNs, we simultaneously consider optical and MIR variability. Notably, when $z > 0.5$, the rest-frame wavelengths corresponding to $W1$ and $W2$ shift into the near-infrared. This may introduce some bias, but it does not compromise the overall reliability of our selection of infrared variability. Moreover, in our final sample

of 211 CL AGN candidates, only 15 sources ($\sim 7\%$) have $z > 0.5$ (the detail is shown in Section 3), corresponding to a minor component of the final sample. Therefore, we have retained the term “MIR” in the manuscript.

Based on the approach of variability in both optical and MIR bands, our work uses spectroscopic and photometric data to achieve a sample of CL AGN candidates. Our main goal is to identify a genuine sample of CL AGNs that transition from a galaxy to a type 1 AGN based on variability. This paper is organized as follows. Section 2 describes the photometric data and our criteria for identifying CL AGNs. Section 3 presents the sample selected by our criteria and evaluates the success rate. In Section 4, we show the results of the spectroscopic analysis and discuss the timescales and physical mechanisms of CL AGNs. A summary and an outlook for future research are given in Section 5. We adopt a Λ CDM cosmology with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$.

2. Data and Criteria

2.1. Spectroscopic and Photometric Surveys

The Sloan Digital Sky Survey (SDSS) is based on a 2.5 m telescope located at the Apache Point Observatory in New Mexico, USA (Gunn et al. 2006). The SDSS program is currently in its fifth phase, with each phase corresponding to different scientific objectives. The SDSS Data Release 18 (DR18, Almeida et al. 2023) includes all the spectroscopic data from the first five phases. The SDSS pipelines compare objects with corresponding templates and classify them into three categories: GALAXY, QSO and STAR (Bolton et al. 2012). The data quality of each spectrum is indicated by a `zWarning` parameter (Stoughton et al. 2002), we select objects with the flag = 0 or 16 to ensure the high spectral quality. There are 2,872,214 galaxy spectra in DR18. The SDSS provides several types of photometric measurements, including point-spread function (PSF), fiber, model, cModel, and Petrosian magnitudes, each tailored to different source morphologies and scientific objectives. In this work, we adopt both PSF and Petrosian magnitudes for distinct purposes. Specifically, PSF magnitudes are used to ensure consistency with the Zwicky Transient Facility (ZTF) light curves, which are based on PSF-fitting photometry and primarily trace nuclear variability assuming a point-like source profile. In contrast, Petrosian magnitudes are employed to represent the total brightness of extended sources, particularly in the context of our parent sample selection, which is based on SDSS sources classified as GALAXY.

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, also known as Guo Shou Jing Telescope) is a 4 m reflecting Schmidt telescope with a field of view of 5° , located at the Xinglong Observatory, China (Cui et al. 2012; Zhao et al. 2012). It captures spectra ranging from 3700 to 9000 Å and can detect celestial objects with a brightness as faint as magnitude 20.5 within a 1.5 hr exposure.

The public Data Release 9 v2.0 (DR9) compiles observations from 2012 to 2023 September, amassing a collection of more than ten million spectra.

The Dark Energy Spectroscopic Instrument (DESI) is the Stage IV ground-based dark energy experiment utilizing the NOIRLab 4 m Mayall telescope located at Kitt Peak (Levi et al. 2013; DESI Collaboration et al. 2016a). DESI is the deepest multi-object spectroscopic survey to date, featuring 5000 fibers on the focal plate and achieving an r -band depth of 23 mag (DESI Collaboration et al. 2016a; Miller et al. 2024). In addition, the light will be split into three channels (blue: 3600–5900 Å, green: 5660–5720 Å and red: 7470–9800 Å) with an excellent spectral resolution (blue: $\lambda/\Delta\lambda \sim 2100$, green: $\lambda/\Delta\lambda \sim 3200$, and red: $\lambda/\Delta\lambda \sim 4100$, DESI Collaboration et al. 2016b, 2022). The deep and high-quality spectra provide a unique opportunity to identify and study these faint and high-redshift galaxies, which is of great significance for understanding the properties of CL AGNs (Zou et al. 2018; Guo et al. 2024).

The ZTF is a time-domain survey with a wide-field camera. It scans the entire Northern sky every 48 hr with a gap of about 3 months between two observation epochs (Bellm et al. 2019). The ZTF data includes information from the g -, r - and i -bands, spanning from 2018 March to the present. Data Release 20 (DR20) was made public in 2024 January. The ZTF is currently the deepest time-domain survey, with a limit magnitude of 20.8 in the g -band and 20.5 in the r -band (Masci et al. 2019). In the ZTF catalog, the `catflags` parameter indicates the quality of photometric data, where a value of 0 signifies high-quality measurements (Masci et al. 2019).

We use MIR photometric data from the Near-Earth Object Wide-field Infrared Survey Explorer Reactivation Mission (NEOWISE-R; Mainzer et al. 2014), which resumed observations in 2013 using the 3.4 and 4.6 μm (W1 and W2) bands. Specifically, we utilize the NEOWISE-R Single Exposure (L1b) Source Table available from the NASA/IPAC Infrared Science Archive (IRSA), which provides calibrated single-epoch photometry. To reduce photometric uncertainties and suppress short-term fluctuations, we bin the W1 and W2 light curves into six-month intervals, following the nominal cadence of NEOWISE observation epochs. We exclude Wide-Field Infrared Explorer (WISE; Wright et al. 2010) data taken before 2013 due to the two-and-a-half-year observational gap and the non-uniform sampling, and restrict our analysis to the uniformly sampled NEOWISE-R data from 2013 onward.

2.2. Sample

In this work, we set the lower redshift limit to 0.1 because the galaxies with lower redshifts may have discrepancies between their spectroscopic and photometric data due to the size of the photometric aperture. The upper redshift limit is set to 0.75 to ensure that the spectrum covers the wavelength

windows for $H\beta$. Within this redshift range, there are a total of 2,186,664 sources classified as `GALAXY` in DR18, with high spectral quality (i.e., `zWarning`=0 or 16, signal-to-noise ratio (SNR) greater than 2). The sources classified as `GALAXY` by the SDSS pipeline indicate that they are either inactive galaxies or galaxies with weak AGNs that were not identified with QSO templates.

Since the limiting magnitude of the ZTF in the g -band is around 20.8, to ensure the completeness of the sample, we consider the sources with SDSS magnitude below 21 in the g -band, based on either PSF or Petrosian magnitudes. In total, this sample comprises 804,735 sources. We cross-match this sample with the ZTF DR20 catalog and discard the sources with an average magnitude greater than 21 or with fewer than 50 photometric data points. As a result, there are 265,684 sources in the final sample for our analysis. The distribution of the number of sources in the sample concerning redshift is shown in Table 1. It can be observed that the number of sources in the final sample decreases with redshift. This is because the galaxies at higher redshifts appear fainter, and most of them are beyond the limit magnitude of ZTF.

2.3. Optical Light Curve Analysis

We use g -band data for analysis because the variations are more pronounced at shorter wavelengths. We first discard the data point with an error greater than twice the average error. After excluding data points with photometric error greater than twice the average error, we apply a 3σ clipping algorithm twice to remove significant outliers. Here, σ denotes the standard deviation of the magnitude values across the light curve. The clipping is based on the deviation from the mean magnitude, iteratively discarding values outside three standard deviations in each round. Finally, we rebin the light curve into 3 days intervals to further minimize systematic error (Masci et al. 2019; Green et al. 2022).

The most widely used definition of variability amplitude for the light curve is proposed by Rodríguez-Pascual et al. (1997) :

$$F_{\text{var}} = \frac{\sqrt{S^2 - \langle \sigma_{\text{err}}^2 \rangle}}{\langle f \rangle}, \quad (1)$$

$$S^2 = \frac{1}{N-1} \sum_{i=1}^N (f_i - \langle f \rangle)^2, \quad (2)$$

and

$$\langle \sigma_{\text{err}}^2 \rangle = \frac{\sum_{i=1}^N \Delta_i^2}{N}, \quad (3)$$

where S^2 represents the variance of flux, $\langle f \rangle$ represents the average flux of light curve, Δ_i denotes the uncertainty associated with each data point, and N is the number of data points.

Table 1
The Distribution of Sample Size Concerning Redshift

Redshift Bins	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.75	Total Objects
N_{GALAXY}	431,824	206,905	268,303	385,319	894,313	2,186,664
$N_{\text{p-sample}}$	419,106	177,341	154,861	38,656	14,771	804,735
N_{ZTF}	151,433	74,870	38,632	396	353	265,684

Note. N_{GALAXY} represents the number of sources classified as GALAXY in the SDSS catalog; $N_{\text{p-sample}}$ stands for the size of the parent sample, and N_{ZTF} means the final sources used for the variability analysis.

For the uncertainty of F_{var} , we adopt the definition by Edelson et al. (2002):

$$\sigma_{F_{\text{var}}} = \frac{1}{F_{\text{var}}} \sqrt{\frac{1}{2N} \frac{S^2}{\langle f \rangle^2}}. \quad (4)$$

From the formula of variability, it is evident that F_{var} is an intrinsic relative variability amplitude that takes into account the errors of the observed data. Therefore, we use $F_{\text{var}} > n \sigma_{F_{\text{var}}}$ to indicate the significance level of the variability signal later on. It is worth noting that here, we are calculating variability and uncertainty in flux space, so before doing so, we need to convert the ZTF magnitude data into flux.

Since the ZTF observational data exhibit strong systematic errors over the same period, relying solely on the parameters F_{var} and $\sigma_{F_{\text{var}}}$ may not effectively filter out the sources with large variability amplitudes caused by systematic errors. Therefore, in addition to these two parameters, we define another set of parameters to select sources with significant variability over a longer timescale.

The sampling interval of ZTF is about 3 days, and there is a seasonal gap between the two observation epochs. Therefore, the time intervals between photometric data points within the same observation epoch are much shorter. Based on the seasonal gap, we divide the ZTF light curve into six segments, each representing an observation period. For each light curve, we calculate the time interval between adjacent data points and select the five largest intervals. Then, we divide the light curve into six bins based on these five intervals. Next, we check the number of photometric data points in each bin. If we find fewer than five data points, we remove that bin and redistribute the remaining data points into six bins with the same method. We randomly select 50,000 sources in our sample, and the maximum time interval for each light curve is shown in Figure 1.

We establish four new parameters, which are:

$$\delta_i = |\langle m \rangle_i - \langle m_{\text{all}} \rangle|, \quad (5)$$

where $\langle m \rangle_i$ is the average magnitude within each observation period, $\langle m_{\text{all}} \rangle$ is the one for the entire light curve. According to the error propagation, the uncertainty of δ_i can be expressed as:

$$\sigma_{\delta_i} = \sqrt{\sigma_{m_i}^2 + \sigma_{m_{\text{all}}}^2}, \quad (6)$$

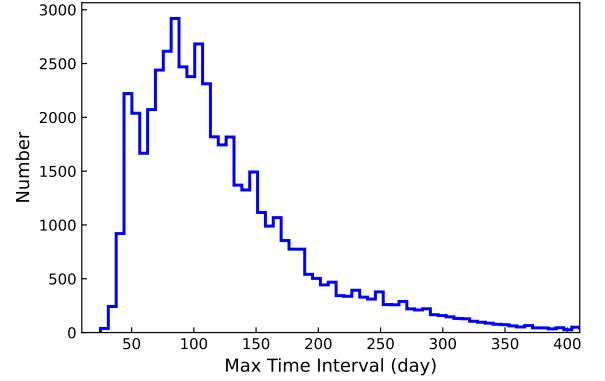


Figure 1. Distribution of the length of the maximum time interval for each light curve. It mostly falls between 50 and 180 days, which aligns well with the observation cycle of ZTF.

where $\sigma_{m_i}^2$, $\sigma_{m_{\text{all}}}^2$ are the variance of the corresponding observation epoch and the entire light curve, respectively. δ_i represents the magnitude change relative to the overall average magnitude for each observation period. We use $\delta_i > k$, σ_{δ_i} to indicate significant variability during a given period. In addition, we use Δg to represent the variability over a long timescale, defined as the difference between the maximum and minimum values of the average g -band magnitudes across all observation periods within the entire observation time window:

$$\Delta g = \langle m \rangle_{\text{max}} - \langle m \rangle_{\text{min}}, \quad (7)$$

we can also calculate the uncertainty of Δg based on the error propagation:

$$\sigma_{\Delta g} = \sqrt{\Delta_{\langle m \rangle_{\text{max}}}^2 + \Delta_{\langle m \rangle_{\text{min}}}^2}, \quad (8)$$

where $\langle m \rangle_{\text{max}}$ and $\langle m \rangle_{\text{min}}$ respectively denote the maximum and minimum value of the average g -band magnitudes for the six periods, and $\Delta_{\langle m \rangle}$ is the error of $\langle m \rangle$.

Considering that Δg is calculated by using the average magnitude of the time bins, short-period variability may be smoothed out. We found the mean uncertainty to be 0.0951 mag, and thus we consider $\Delta g > 0.3$ mag (corresponding to $3\sigma_{\Delta g}$) as an indicator of long-term variability.

2.4. Infrared Variability

In addition to optical data, we also consider MIR light curves to improve the success rate in the search for CL AGN candidates. The MIR emission at 3.4 and 4.6 μm primarily originates from hot dust heated by the AGN (some form polar dust in ionization cones or outflows, particularly in type 1 AGNs; Hönig et al. 2013; Rhee et al. 2016), which is often associated with the dusty torus in unification models (Ramos Almeida & Ricci 2017). The MIR light curves typically exhibit a time delay compared to the optical emission from the accretion disk, reflecting the light-travel time across the dust sublimation radius (Orosz et al. 2007). These delays can vary depending on the geometry and dynamics of the dust distribution, including potential non-Keplerian motions driven by radiation pressure or turbulence (Du et al. 2016). Nevertheless, MIR variability effectively traces changes in the accretion rate of the central engine. Moreover, since the opacity of dust to photons decreases sharply with increasing wavelength, infrared radiation is much less affected by dust extinction compared to optical radiation. Consequently, if the CL phenomenon is caused by obscuration change, the infrared variability should correspond to a larger optical variability (Sheng et al. 2017).

We only use the data where `ph_qual` is equal to A or B, indicating good photometric quality. Next, we exclude the points with `qi_fact` < 1 (corresponding to lower image quality). Finally, we rebin the data into six-month intervals and represent the magnitude in each bin by the median value.

Following Sheng et al. (2017, 2020), we define ΔW to quantify the MIR variation:

$$\Delta W = W_{\max} - W_{\min}, \quad (9)$$

and we calculate the uncertainty of ΔW as mentioned above:

$$\sigma_{\Delta W} = \sqrt{\Delta_{W_{\max}}^2 + \Delta_{W_{\min}}^2}, \quad (10)$$

where $W_{\max}$ and $W_{\min}$ represent the maximum and minimum magnitudes in $W1$ and $W2$ bands, and $\Delta_{W_{\max}}$, $\Delta_{W_{\min}}$ is the corresponding error of $W_{\max}$ and $W_{\min}$, respectively.

Sheng et al. (2017, 2020) used $\Delta W > 0.4$ for $W1$ or $W2$ band as one of the criteria for identifying CL AGNs. We calculate the uncertainties of our sample, with the average uncertainties in the $W1$ - and $W2$ -bands being 0.0334 and 0.0391, respectively. For the completeness of our sample, we conservatively take $\Delta W > 0.3$ mag for $W1$ or $W2$ band to pick up the sources with significant MIR variation.

2.5. Criteria

As mentioned previously, Type 1 AGNs are typically associated with significant variability. To filter for sources

with significant variability from those classified as `GALAXY`, we randomly select QSOs from the SDSS DR16 Quasar Catalog (Lyke et al. 2020) and Type 2 AGNs from Million Quasar Catalog v7.2 (Flesch 2021) with different redshifts as a control sample to study their variability amplitudes, thereby determining the criteria for selecting highly variable sources. The result is shown in Figure 2. It is found that there is a clear distinction between QSOs and Type 2 AGNs when $F_{\text{var}} > 12\sigma_{F_{\text{var}}}$. To ensure that the selected sample includes only sources with significant variability, we increase the threshold to $F_{\text{var}} > 15\sigma_{F_{\text{var}}}$. Additionally, to ensure the reliability of the variability signals in the selected sources, we further impose restrictions on the minimum value of F_{var} and the upper limit of $\sigma_{F_{\text{var}}}$. For high-redshift sources, the photometric data probably have larger errors and lower SNR. Therefore, the corresponding F_{var} is smaller than low-redshift sources, indicating that the parameter n , which represents the optical variability signal, is also smaller. We found that QSOs can be identified with a smaller n at a higher redshift. Similarly, we examine the value of k in $\delta_i > k\sigma_{\delta_i}$. The parameters in our criteria for selecting CL AGN candidates are given in Table 2.

To enhance the success rate of this method, we incorporate MIR variability as an additional selection criterion alongside optical variability. MIR variability serves as a distinctive feature of AGNs, further strengthening the reliability of the identified CL AGN candidates.

Recently, Guo et al. (2024) confirmed 56 CL AGNs through cross-matching SDSS DR16 and Dark Energy Spectroscopic Instrument Early Data Release (DESI EDR) spectra. We use these 56 sources as a control sample to establish our criteria. Among these 56 sources, six lack ZTF observational data, one has only r -band data, and 13 sources have either a g -band average magnitude greater than 21 or fewer than 50 data points. Therefore, only 36 sources are available for our analysis. Using this criterion, we selected 30 out of the 36 CL AGNs. Among the remaining six, five were in a “turn-off” state where Type 2 AGNs are with insignificant variability, while one source in a “turn-on” state was not selected due to its large error bars corresponding to the data points. The light curve examples of the three classes are shown in Figure 3. The test results demonstrate that our criteria are highly effective in selecting sources with extreme variability.

3. Results

3.1. CL AGN Candidates

We select 352 sources with strong variability using our criteria, but they include some special sources that need to be excluded, such as blazars and misclassified stars. Blazars are considered a type of source with a jet pointing toward our line of sight (Blandford & Rees 1978). They often exhibit rapid and irregular variability within a short period and lack prominent

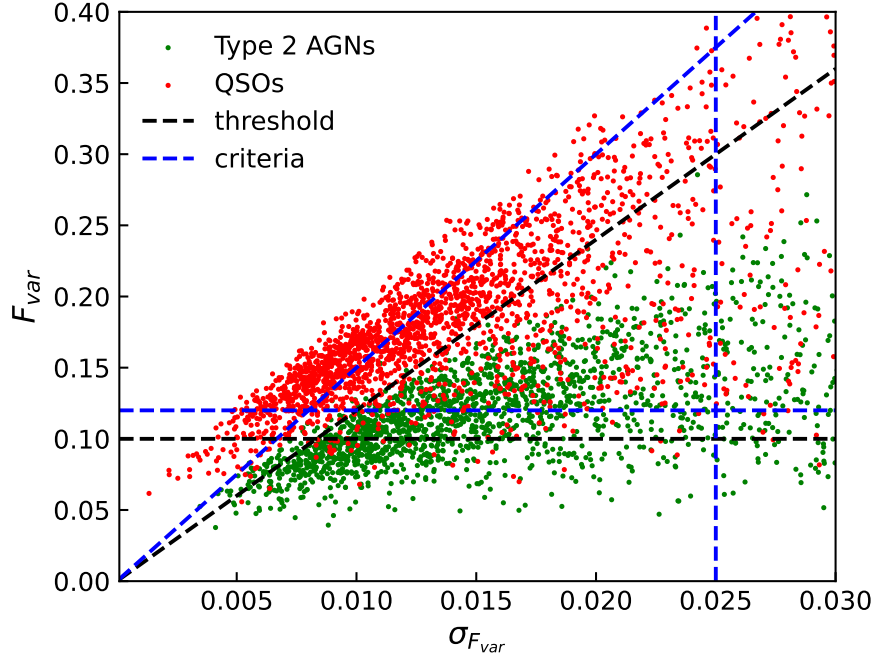


Figure 2. The optical variability threshold between Type 2 AGNs and QSOs with $0.1 < z < 0.3$. The green dots and red dots represent the Type 2 AGNs and QSOs, respectively. The black dashed diagonal line represents $F_{\text{var}} > 12\sigma_{F_{\text{var}}}$, indicating the variability threshold between Type 2 AGNs and QSOs. The black horizontal dashed line at $F_{\text{var}} = 10\%$ helps to eliminate the overlap of red and green points at low variability amplitudes. The blue dashed lines represent our criteria that the diagonal line is $F_{\text{var}} > 15\sigma_{F_{\text{var}}}$, the horizontal line is $F_{\text{var}} = 12\%$ and the vertical line is $\sigma_{F_{\text{var}}} < 2.5\%$ to exclude sources with excessively large uncertainties.

Table 2
Criteria for Each Redshift Bin

Redshift Bins	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.75
F_{var}	$>12\%$	$>12\%$	$>8\%$	$>5\%$
$\sigma_{F_{\text{var}}}$	$<2.5\%$	$<2.5\%$	$<2.5\%$	$<2.5\%$
n	15	15	10	5
Δg	>0.3	>0.3	>0.3	>0.3
k	10	10	10	10
$\Delta W1(W2)$	>0.3	>0.3	>0.3	>0.3

Note. n represents the coefficient for $F_{\text{var}} > n\sigma_{F_{\text{var}}}$, while k represents the coefficient for $\delta_i > k\sigma_{\delta_i}$, and $\Delta W1(W2) > 0.3$ means W1 or W2 variation greater than 0.3 mag.

emission or absorption lines in their spectra (Giommi et al. 1995; Aharonian et al. 2007; Paliya et al. 2017). Due to their unique characteristic, we use Simbad³ to exclude these sources. We identify a total of 139 blazars (or blazar candidates) and 2 stars. Finally, 211 sources are selected as CL AGN candidates. All information about these candidates can be found in Table 3.

³ <http://simbad.harvard.edu/>

3.2. Success Rate

To evaluate the success rate of this method in searching CL AGNs, we cross-match the candidate sample with the SDSS DR18 QSO catalog, LAMOST DR9 v2.0, and DESI DR1. We are focusing on the spectra from the year 2016, which corresponds to the MJD of approximately 57000, within two years before the commencement of ZTF observation, to investigate the variability genuinely caused by changes in types (Wang et al. 2024b). To ensure the accuracy of our subsequent fitting results, we require the average S/N of the spectrum to be greater than 3. We retrieve the LAMOST spectra for 12 objects and the DESI spectra for 63 objects.

We adopt the method proposed by MacLeod et al. (2019) and Green et al. (2022) to confirm CL AGNs, using the significance parameter:

$$N_{\sigma} = \frac{f_{\text{bright}} - f_{\text{dim}}}{\sqrt{\sigma_{\text{bright}}^2 + \sigma_{\text{dim}}^2}}, \quad (11)$$

where f and σ denote the flux and its uncertainty in units of $\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$. To mitigate inconsistencies due to varying wavelength coverage and resolution among different surveys, we resample all spectra onto a common wavelength grid with $2 \text{\AA}$ per pixel. The resulting $N_{\sigma}(\text{H}\beta)$ array is then smoothed with a median filter using a kernel size of 16 pixels

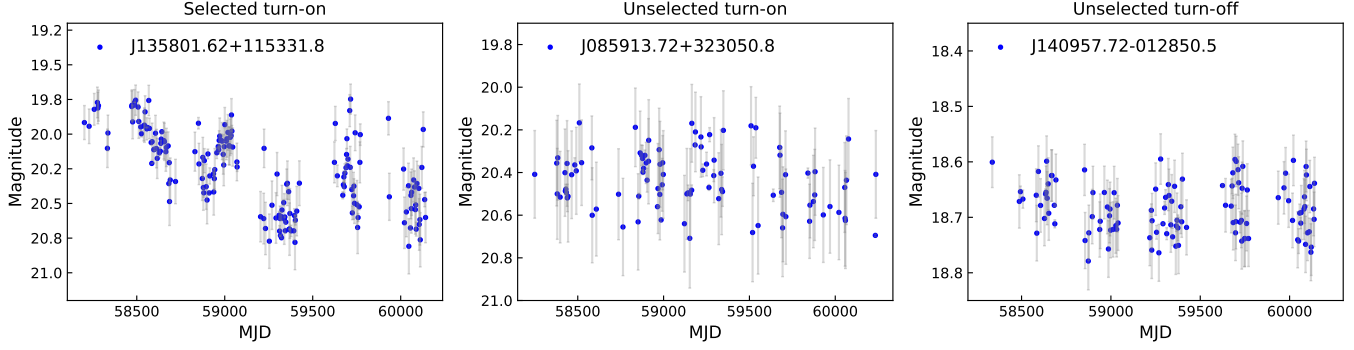


Figure 3. Example for selecting and unselecting light curves with our criteria. The left panel shows the light curve of the sources selected by our criteria, exhibiting significant variability. In the middle is the example in the “turn-on” state that was not selected, possibly due to large error bars. However, visually, the variability in its light curve does not appear significant. On the right is the example source in the “turn-off” state, characteristic of a type 2 AGN, which typically does not show significant variability.

Table 3
The CL Candidates in this Work

Name (1)	R.A. (2)	Decl. (3)	Redshift (4)	Plate (5)	MJD (6)	Fiberid (7)	F_{var} (8)	$\sigma_{F_{\text{var}}}$ (9)	Δg (10)	$\Delta W1$ (11)	$\Delta W2$ (12)
J111824.18–005704.4	169.6008	–0.9512	0.3144	279	51984	57	0.211	0.0148	0.5971	0.37	0.48
J115547.64+004852.0	178.9485	0.8144	0.2089	284	51943	613	0.2317	0.014	0.4205	0.3	0.37
J132045.25–002449.6	200.1885	–0.4138	0.2208	296	51984	168	0.2086	0.0123	0.5395	0.26	0.37
J121244.50–005741.2	183.1854	–0.9615	0.2922	324	51616	140	0.1713	0.0109	0.5155	0.37	0.75
J120732.71–013819.3	181.8863	–1.6387	0.3235	332	52367	323	0.2125	0.0137	0.5688	0.58	0.68
J154724.52+001938.9	236.8522	0.3275	0.2125	342	51691	494	0.2076	0.012	0.4758	0.57	0.81
J222322.45+004619.2	335.8436	0.772	0.2208	375	52140	454	0.192	0.0101	0.4252	0.32	0.35
J000441.23+000711.2	1.1718	0.1198	0.1075	387	51791	34	0.1306	0.0067	0.3454	0.55	0.89
J005231.06+005505.3	13.1295	0.9181	0.2036	394	51913	535	0.1422	0.0073	0.3123	0.36	0.35
J022505.36+000540.5	36.2723	0.0946	0.2134	406	51869	112	0.1496	0.0084	0.3124	0.77	0.81

Note. Columns (1)–(7) are the basic information of the candidates, sourced from SDSS. The object can be uniquely identified based on columns (5)–(7). Parameters (8)–(12) were obtained using our method and are crucial for filtering sources exhibiting variability. The full Table 3 is at <https://doi.org/10.57760/sciencedb.j00167.00031>.

(corresponding to $32 \text{ \AA}$) to reduce noise and enhance broad-line structures. We identify the maximum value of the smoothed N_σ array within the $H\beta$ region ($4750\text{--}4940 \text{ \AA}$) to evaluate the significance of spectral variation. Before calculating N_σ , we perform spectral fitting for the spectra from three different surveys. The flux from the SDSS spectra is used as the standard to calibrate the LAMOST and DESI fluxes based on $[O III]$ ($5007 \text{ \AA}$), as detailed in Section 3.3. Previous works have set the value of $N_\sigma = 3$ as the threshold between CL and non-CL (NCL) AGNs. We adopt the criteria for both $H\beta$ and $H\alpha$ emission lines to identify the CL phenomenon. We find that seven sources in those 11 sources with LAMOST spectra and 28 targets in those 63 targets with DESI spectra have $N_\sigma > 3$. But this method depends on the spectral SNR, we also conduct a visual inspection of these SDSS and LAMOST spectra and successfully identify an object exhibiting CL phenomenon for $H\beta$ (J111000.32+080415.7). There are 36 CL AGNs confirmed by comparing the repeat spectra, which

means the success rate of the method for searching CL AGNs is $\approx 50\%$. The results, along with some other properties, are listed in Table 4. Figure 4 shows the spectra from SDSS and LAMOST (DESI), optical and MIR light curves of the CL AGNs confirmed in this work, and Figure 5 for an example of NCL AGNs. The CL AGN identified by visual inspection is shown in Figure 6.

In addition, among our candidate sample that is not confirmed through repeat spectroscopy, we identify 13 sources that had previously been reported in the literature. Of these, 12 have been confirmed as CL AGNs, while 1 shows no clear evidence of CL behavior. These sources are listed in Table 5. We note that there is an object (J110423.21+634305.3) identified by two spectra without variability, and the dates of spectroscopy fall outside the period covered by the optical and MIR light curves. This object is reported as a turn-off CL AGN by Yang et al. (2018), though comparing the two spectra from the SDSS databases. It is a quasar at $MJD = 52370$ and

Table 4
Properties of Confirmed CL AGNs in this Work

SDSS Name	z	MJD _{SDSS}	MJD _{new}	σ_* (km s ⁻¹)	$\log L_{5100}^B$ (erg s ⁻¹)	$\log L_{5100}^D$ (erg s ⁻¹)	$\log M_{BH}$ ($M_\odot$)	H β	H α
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
J115547.64+04851.8	0.2089	51662	59648	282.54 $\pm$ 170	43.89 $\pm$ 0.01	43.15 $\pm$ 0.04	9.02 $\pm$ 0.06	on	on
J092108.59+445450.8	0.1561	52312	59520	242.56 $\pm$ 42	42.98 $\pm$ 0.02	42.68 $\pm$ 0.03	7.59 $\pm$ 0.04	on	on
J101152.99+544206.5	0.2465	57073	59601	141.79 $\pm$ 36	43.56 $\pm$ 0.01	42.85 $\pm$ 0.02	7.59 $\pm$ 0.02	on	on
J155259.95+210247.0	0.1717	53557	59689	158.97 $\pm$ 75	43.18 $\pm$ 0.01	42.60 $\pm$ 0.04	7.50 $\pm$ 0.01	on	on
J110423.21+634305.5	0.1643	54498	59600	88.48 $\pm$ 67	42.96 $\pm$ 0.02	42.23 $\pm$ 0.02	7.77 $\pm$ 0.03	on	on
J141713.82+372525.0	0.2124	53084	59656	188.00 $\pm$ 22	42.78 $\pm$ 0.07	42.60 $\pm$ 0.05	8.05 $\pm$ 0.08	NCL	on
J164313.15+261827.0	0.1372	53167	59401	169.99 $\pm$ 20	42.89 $\pm$ 0.02	42.78 $\pm$ 0.02	8.89 $\pm$ 0.19	on	NCL
J155440.25+362952.1	0.2368	53172	59742	229.44 $\pm$ 35	43.64 $\pm$ 0.01	42.62 $\pm$ 0.41	8.08 $\pm$ 0.06	on	on
J214327.60+110111.3	0.2844	52221	59525	254.56 $\pm$ 33	43.05 $\pm$ 0.02	42.62 $\pm$ 0.27	8.16 $\pm$ 0.15	NCL	on
J005231.08+05505.2	0.2036	51812	59568	211.76 $\pm$ 19	42.9 $\pm$ 0.03	42.8 $\pm$ 0.02	8.15 $\pm$ 0.04	NCL	on
J22505.35+00540.6	0.2134	51817	59600	121.10 $\pm$ 65	43.33 $\pm$ 0.01	43.03 $\pm$ 0.02	7.98 $\pm$ 0.10	on	NCL
J21405.33-55118.4	0.5306	56662	59604	637.38 $\pm$ 290	44.01 $\pm$ 0.17	43.69 $\pm$ 0.03	9.30 $\pm$ 0.23	on	NCL
J222322.46+04619.2	0.2208	52140	59481	251.04 $\pm$ 28	43.16 $\pm$ 0.02	42.98 $\pm$ 0.02	8.45 $\pm$ 0.04	on	on
J230428.32+05701.1	0.3168	52606	59481	544.71 $\pm$ 180	43.00 $\pm$ 0.04	42.67 $\pm$ 0.07	8.20 $\pm$ 0.05	NCL	on
J212039.77-05644.2	0.2508	52932	59479	460.76 $\pm$ 76	43.31 $\pm$ 0.01	42.88 $\pm$ 0.14	8.11 $\pm$ 0.02	on	on
J084149.39-01031.4	0.1284	58932	59612	189.21 $\pm$ 20	43.04 $\pm$ 0.06	42.68 $\pm$ 0.02	8.13 $\pm$ 0.08	on	NCL
J111000.34+80415.6	0.1161	52723	59567	122.92 $\pm$ 17	42.75 $\pm$ 0.06	42.38 $\pm$ 0.05	7.90 $\pm$ 0.10	on	NCL
J121520.30+310509.2	0.3603	53799	59581	322.41 $\pm$ 45	43.55 $\pm$ 0.17	43.49 $\pm$ 0.01	7.88 $\pm$ 0.67	on	NCL
J091254.05+21555.1	0.163	58928	59646	148.04 $\pm$ 13	43.19 $\pm$ 0.02	42.84 $\pm$ 0.01	7.65 $\pm$ 0.09	on	NCL
J154841.86+41357.4	0.1721	54559	59356	169.76 $\pm$ 65	42.73 $\pm$ 0.04	42.19 $\pm$ 0.13	7.80 $\pm$ 0.07	NCL	on
J075145.14+411536.0	0.4290	55182	59551	883.97 $\pm$ 140	44.04 $\pm$ 0.00	44.24 $\pm$ 0.00	7.46 $\pm$ 0.02	on	on
J153502.28+345538.3	0.1307	53144	59728	380.66 $\pm$ 48	43.52 $\pm$ 0.00	42.81 $\pm$ 0.03	7.65 $\pm$ 0.01	on	on
J221306.74+11519.8	0.5426	52912	59490	318.76 $\pm$ 360	44.07 $\pm$ 0.01	43.8 $\pm$ 0.08	8.58 $\pm$ 0.09	on	NCL
J115547.64+04851.8	0.2089	51662	59319	282.54 $\pm$ 170	43.79 $\pm$ 0.01	43.15 $\pm$ 0.04	9.05 $\pm$ 0.01	NCL	on
J160749.75+544055.9	0.2332	56430	59312	134.62 $\pm$ 20	43.26 $\pm$ 0.02	42.69 $\pm$ 0.03	8.02 $\pm$ 0.22	on	NCL
J092317.54+420201.0	0.2384	52674	59538	156.27 $\pm$ 49	43.24 $\pm$ 0.03	43.35 $\pm$ 0.02	7.66 $\pm$ 0.08	off	NCL
J145526.11+350224.7	0.2782	53121	59696	207.62 $\pm$ 53	42.94 $\pm$ 0.02	43.23 $\pm$ 0.09	7.9 $\pm$ 0.15	NCL	off
J132045.24-02449.7	0.2208	51578	59653	304.53 $\pm$ 27	42.97 $\pm$ 0.14	43.11 $\pm$ 0.07	8.15 $\pm$ 0.04	off	off
J151215.74+000813.1	0.2199	51996	59553	250.63 $\pm$ 37	42.58 $\pm$ 0.02	43.26 $\pm$ 0.00	8.32 $\pm$ 0.12	NCL	on
J083132.25+364617.2	0.1950	52312	57366	233.69 $\pm$ 24	43.38 $\pm$ 0.03	42.81 $\pm$ 0.09	8.24 $\pm$ 0.07	on	on
J091459.15+050243.4	0.1425	52652	58878	162.34 $\pm$ 23	43.40 $\pm$ 0.01	42.75 $\pm$ 0.04	7.92 $\pm$ 0.04	on	on
J092725.37+113419.6	0.1347	53050	58487	138.38 $\pm$ 16	42.66 $\pm$ 0.02	42.35 $\pm$ 0.02	7.80 $\pm$ 0.07	NCL	off
J095137.27+341612.2	0.1322	53388	56632	101.11 $\pm$ 20	42.60 $\pm$ 0.07	42.02 $\pm$ 0.21	7.72 $\pm$ 0.08	on	on
J104110.90+544953.2	0.1579	52368	57043	109.04 $\pm$ 23	42.97 $\pm$ 0.02	42.82 $\pm$ 0.03	7.74 $\pm$ 0.06	NCL	off
J110200.11+572250.5	0.1418	52427	59231	193.92 $\pm$ 20	43.13 $\pm$ 0.03	42.74 $\pm$ 0.03	8.23 $\pm$ 0.05	NCL	on
J144754.23+283324.0	0.1637	53764	57070	148.05 $\pm$ 13	43.55 $\pm$ 0.03	42.63 $\pm$ 0.02	7.48 $\pm$ 0.04	on	NCL

Note. Column (1): SDSS object name; (2): redshift; (3) and (4): MJDs of the SDSS and new spectra (LAMOST or DESI), respectively; (5): stellar velocity dispersion (σ_*) measured from the dim state spectrum; (6) and (7): $\log L_{5100}$ in the bright and dim states; (8): black hole mass ($\log M_{BH}$) estimated from the H α or H β line in the bright state; (9) and (10): states of the H β and H α lines (on/off/NCL).

then classified as a galaxy by the SDSS pipeline at MJD = 54498, but its optical and MIR light curve display a significant variability from about MJD = 57000, which means it may turn on again, so-called “recurrent CL AGN” (we confirm it with DESI spectrum, the detail see Section 4.5).

In this work, we confirm a total of 87 objects in the CL AGN candidate sample, of which 48 are classified as CL AGNs and 39 as NCL AGNs. Finally, we will simply discuss the confirmed NCL AGNs. By visually inspecting the optical and MIR light curves, with the date of the second spectral

observation (the red dashed line in the top panel of Figure 5), we find most of them may still in a dim state during the second observation (e.g., J010747.92+242848.7, J091254.06+021555.0). For the other targets, their SDSS spectrum has a weak H α broad component, meaning that its variability may be from AGN but not CL behavior (e.g., J111824.19–05704.3, J120459.00+153513.8). A detailed discussion of this source can be found in López-Navas et al. (2023b). If we further refine the timing of the spectral observations, we believe our success rate will be even higher.

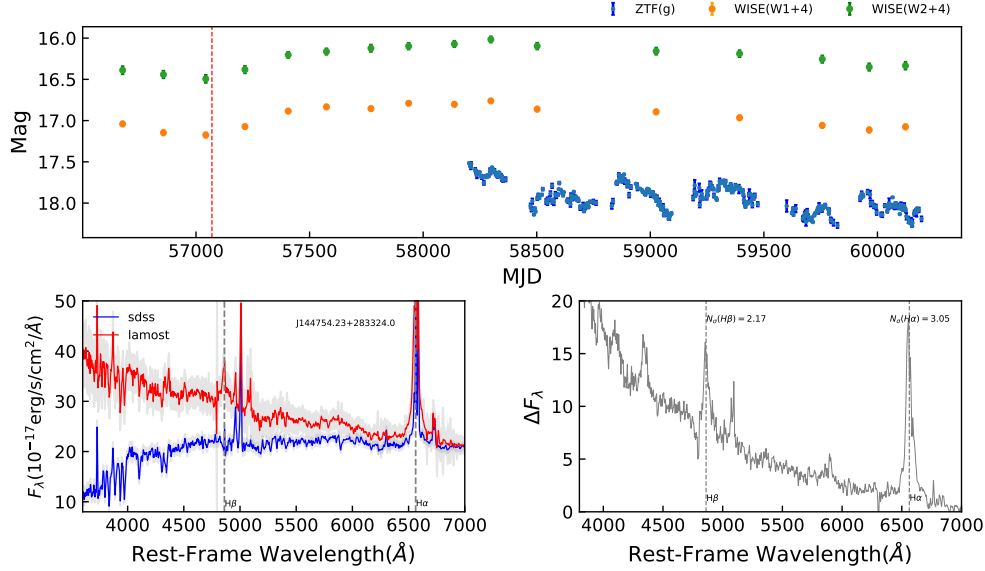


Figure 4. The spectra and light curves for identified CL AGNs. The top panel shows the optical and MIR light curves in blue dots and orange, green dots, respectively. The red dashed line represents the MJD of LAMOST observation. The bottom left panel shows the SDSS spectra (blue) and LAMOST spectra (red), and the black dashed lines are the positions of H β and H α . The bottom right panel is the residual of two spectra. The full Figure 4 is at <https://doi.org/10.57760/sciencedb.j00167.00031>.

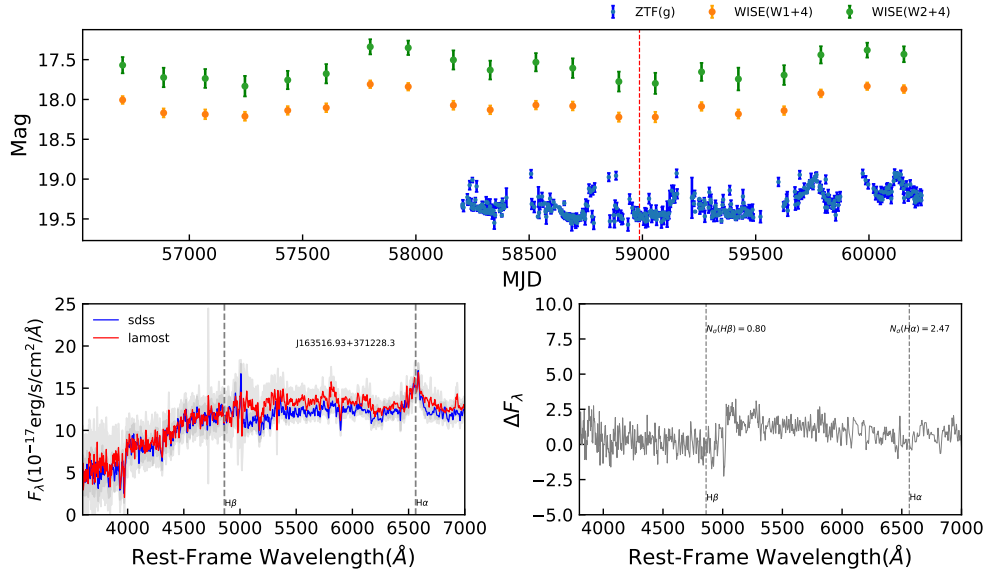


Figure 5. An example of the spectra and light curves for identified NCL AGNs.

3.3. Spectral Analysis

Because the spectra originate from various telescopes, we first need to calibrate their fluxes. Generally, we assume that narrow emission lines do not change over a timescale of decades because the NLR has a very large spatial scale, typically reaching several kiloparsecs (Bennert et al. 2002; Dempsey & Zakamska 2018), which implies that the timescale for changes in the flux of narrow emission lines is on the order of a thousand years or more. We select the flux of [O III]

(5007 Å) as the calibration standard and used the flux from SDSS as a reference to calibrate the LAMOST and DESI spectral fluxes.

The spectral fitting tool we employed is the latest version of the public code `PyQSOFit`⁴ (Guo et al. 2019; Shen et al. 2019; Ren et al. 2024), which includes a prior-informed Principal Component Analysis-based module for separating

⁴ <https://github.com/legolasov/PyQSOFit>

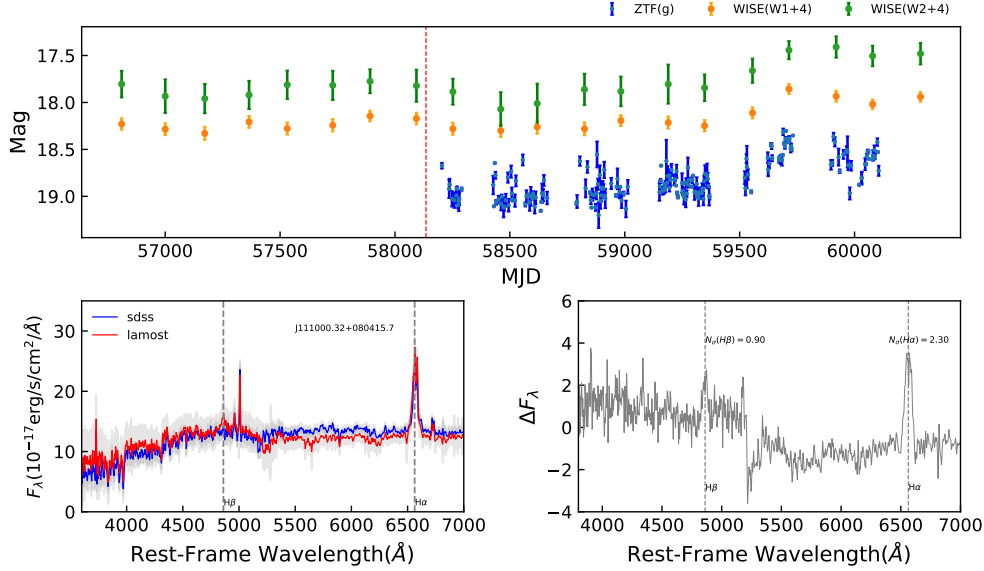


Figure 6. The spectra and light curves for the CL AGN identified by visual inspection.

AGN and host galaxy components. Specifically, we employ the first ten principal components for both galaxies and quasars, derived from the SDSS spectral library (Yip et al. 2004a, 2004b), to model the composite spectrum. After removing the host galaxy contribution, we fit the AGN residual with a power-law continuum and an Fe II emission template (Boroson & Green 1992), using designated continuum windows free of strong emission lines (Shen et al. 2011; Guo et al. 2019). The emission-line fitting is then performed on the continuum-subtracted spectra, treating the H β and H α regions separately. For each narrow line, we use a single Gaussian, while the broad components are modeled with three Gaussians to allow for profile asymmetries.

We fit the spectra for a total of 11 confirmed CL AGN candidates with LAMOST spectra and 63 with DESI spectra. For the sources repeated in previous studies, we directly adopt the results they provided. Our main focus is on fitting the stellar velocity dispersion (σ_*), flux, L_{5100} and other information of emission lines. It is noteworthy that the σ_* primarily refers to the fitting value in the dim state, while the full width at half maximum (FWHM) of the broad emission lines is based on the brightening spectra. This is because, for CL AGNs, the quiescent spectra offer clean information about the host galaxy, which can be contaminated by the central engine during the active state (Jin et al. 2022). The fitting results are shown in Table 4, and Figure 7 provides an example of a fitting diagram.

4. Discussion

Currently, there are many hypotheses explaining the CL phenomenon. The most prevalent ones include sudden changes in the accretion rate of the central black hole, transient events (such as supernovae and TDE), and the movement of

obscuring material into or out of the line of sight. Although these theories can explain certain CL phenomena to some extent, all have their issues, such as timescales and the shapes of the light curves. Therefore, the fundamental mechanism behind the CL phenomenon remains unclear. Here, we briefly discuss the physical mechanisms behind the 48 CL AGNs identified in this work.

4.1. Timescale

The timescale issue of CL behavior is a key factor in studying its physical mechanism and has been one of the persistent challenges in this field. Previous studies have shown that the timescale of CL is typically between 1 and 20 yr (Yang et al. 2018; López-Navas et al. 2022; Guo et al. 2024; Wang et al. 2024b), marked by the appearance or disappearance of broad emission lines in two spectra. There are also some extreme cases with timescales of a few months (Trakhtenbrot et al. 2019; Zeltyn et al. 2022; Yang et al. 2023). This largely depends on the timing of spectroscopic observations and has a significant element of chance. Therefore, the calculated timescale can be considered as an upper limit for the CL phenomenon. As shown in Figure 8, the CL timescales in our sample range from 1.7 to 18.1 yr, consistent with the conclusions in previous works.

By assuming that the obscuring material (dusty cloud) is in a Keplerian orbit outside the BRL, we can estimate the cross time of the cloud as LaMassa et al. (2015):

$$t_c = 0.07 \left[\frac{r_{\text{orb}}}{1 \text{ lt-day}} \right]^{3/2} \left[\frac{M_{\text{BH}}}{10^8 M_{\odot}} \right]^{-1/2} \arcsin \left[\frac{r_{\text{src}}}{r_{\text{orb}}} \right] \text{ yr}, \quad (12)$$

where r_{src} and r_{orb} are the sizes of the BLR and the obscuring material, respectively. Substituting $r_{\text{src}} = 35 \text{ lt-day}$, $r_{\text{orb}} \geq 3r_{\text{src}}$ and

Table 5
Properties of Confirmed CL AGNs Compared with the Reported CL AGN Sample

SDSS Name	z	MJD _{SDSS}	MJD _{new}	σ_* (km s ⁻¹)	$\log L_{5100}^B$ (erg s ⁻¹)	$\log L_{5100}^P$ (erg s ⁻¹)	$\log M_{BH}$ ($M_\odot$)	H β	H α	References
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
J075544.35+192336.3	0.1082	53315	59529	164.79 ± 11	44.34	42.38 ± 0.05	8.5 ± 0.1	on	NCL	Lyu et al. (2022)
J091531.04+481407.6	0.1005	52637	58219	120	43.61 ± 0.01	43.06	7.8	on	on	Frederick et al. (2019)
J100323.46+352503.8	0.1189	53389	57867	186.82 ± 15	43.66	42.55 ± 0.01	...	on	on	Yang et al. (2018)
J102038.50+243708.3	0.1894	53734	60059	195.68 ± 20	45.1	43.85	9.15	on	on	Wang et al. (2024b)
J111829.64+320359.9	0.366	53431	56367	189.9	43.75	43.26 ± 0.04	7.52 ± 0.11	off	NCL	Yang et al. (2018)
J112939.07+365300.9	0.1995	55673	59603	210.49 ± 99	...	42.48 ± 0.05	...	on	on	López-Navas et al. (2023b)
J115039.31+363258.2	0.3401	53436	57422	162.82	43.59	42.88 ± 0.20	7.78 ± 0.10	off	NCL	Yang et al. (2018)
J131930.75+675355.4	0.1664	51988	57867	96.27 ± 17	43.49	42.41 ± 0.25	...	on	NCL	Yang et al. (2018)
J132457.29+480241.2	0.2721	52759	56805	...	44.34	...	8.51	off	NCL	MacLeod et al. (2016)
J222559.66+201944.7	0.1554	56189	59808	214.29 ± 13	44.48	43.62	8.12	on	on	Wang et al. (2024b)
J224657.69-003242.5	0.4162	52590	59404	272.28 ± 40	...	43.26 ± 0.57	...	on	NCL	Guo et al. (2024)
J235720.13-005829.9	0.3391	52203	59190	157.80 ± 53	43.3	42.25	7.61	on	on	Zel'tyn et al. (2024)
J120459.00+153513.8	0.2209	53467	59603	85.86 ± 28	...	42.95 ± 0.04	...	NCL	NCL	López-Navas et al. (2023b)

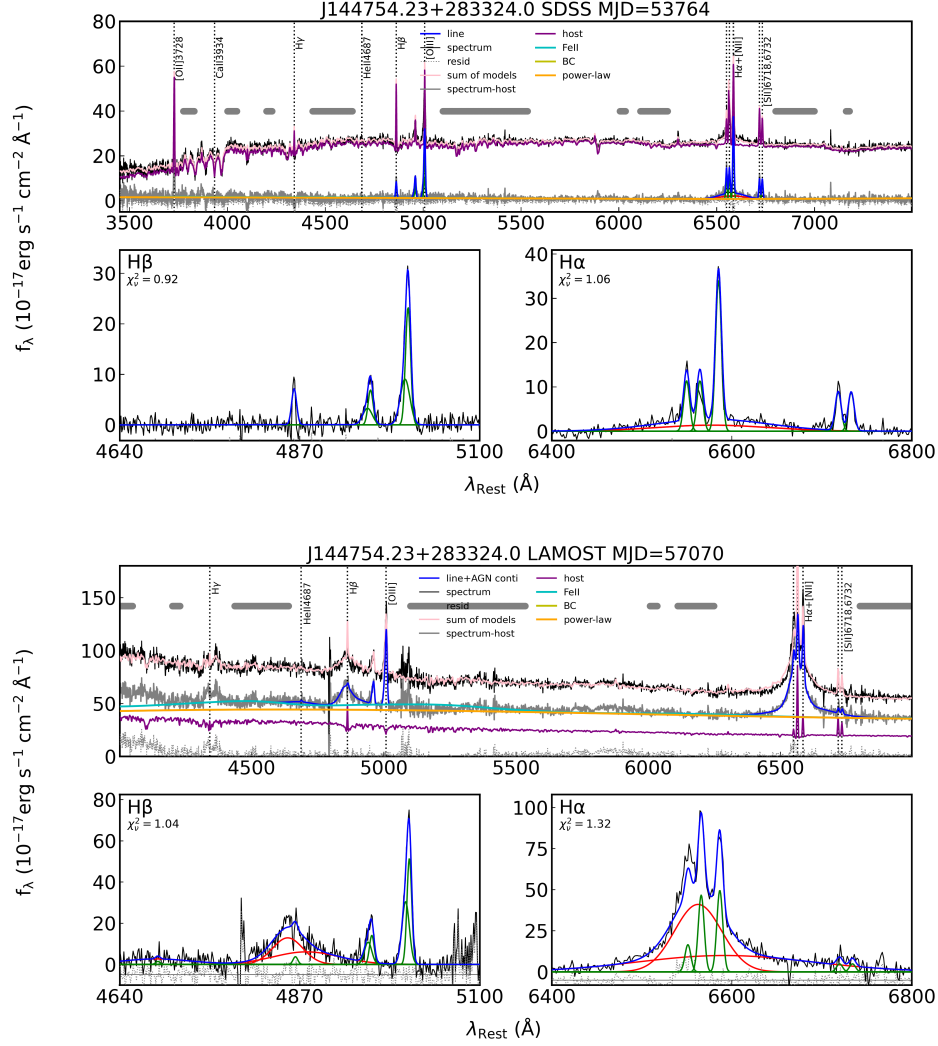


Figure 7. Example of spectral decomposition for dim (top) and bright (bottom) states of J144754.23+283324.0 using PyQSOFit. The upper panels exhibit the full modeling results, where the original spectra, host galaxy component, host-subtracted spectrum, AGN power-law continuum, and FeII component are shown in black, purple, gray, and cyan, respectively. The blue solid lines represent the sum of emission-line models. The lower panels zoom in to the H β (left) and H α (right) regions to display the result of the line fit. The green and red lines represent individual narrow and broad Gaussians, respectively.

$\left[\frac{M_{\text{BH}}}{M_{\odot}}\right] = 1.7$ into Equation (12) (LaMassa et al. 2015), we obtain $t_c \geq 20$ yr. The several decades contradict the observed months-to-years timescale of the CL phenomenon. The other evidence suggesting that the obscure model may not be correct mainly includes: (1) MIR variability is often coordinated with optical changes, strongly favoring intrinsic luminosity changes over variable obscuration (e.g., Sheng et al. 2017, 2020); (2) the reddening test that the broad emission lines of the dim state spectra are inconsistent with the after-extinction bright state spectra (LaMassa et al. 2015; Merloni et al. 2015); (2) in some cases where broad emission lines disappear in the optical, the X-ray spectra still show no significant absorption features, suggesting that the central engine remains visible at high energies and is not obscured by new intervening material (Husemann et al. 2016).

4.2. Detection Rate

Besides the timescale, we also roughly estimate the detection rate of CL behavior in galaxies. We identify 211 sources with strong variability in ZTF light curves from 2018 to now, among 265,484 objects classified as GALAXY in SDSS DR18. We consider these as CL AGN candidates. Among the 74 sources confirmed, we achieve a success rate of $\sim 50\%$. The detection rate of our CL candidates is ~ 0.0008 (211/265, 484). If we multiply this by the success rate in confirming CL behavior, our result indicates a probability of a detection rate of 0.04%. This result is highly consistent with the findings of Yang et al. (2018) using SDSS and LAMOST repeat spectra. However, Temple et al. (2023) discovered 21 CL AGNs among 749 X-ray-selected AGNs, corresponding to

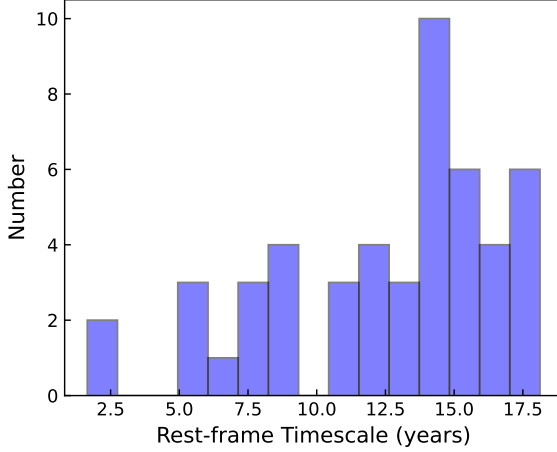


Figure 8. Distribution of the rest-frame timescale of the confirmed CL AGNs. The timescale is defined as the time interval between the two spectra. This time can be considered as the upper limit of the CL timescale.

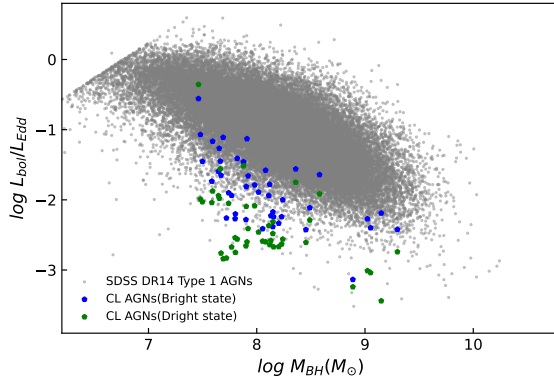


Figure 9. Distribution of our CL AGNs on the $L_{\text{bol}}/L_{\text{Edd}}-M_{\text{BH}}$ plane. The blue points represent the Eddington ratio in the bright state, while the green points represent the Eddington ratio in the dim state, and the gray pentagon is type 1 AGNs with $0.1 < z < 0.75$ from Rakshit et al. (2020). The Eddington ratios of CL AGNs are relatively low, and the Eddington ratios in the bright state are significantly higher than those in the dim state.

a discovery rate of 0.3%. Guo et al. (2024) found an $H\beta$ CL occurrence rate of 0.4% using repeat spectra from SDSS and DESI, and Wang et al. (2024b) yielded a result of 0.3% based on damped random walks of optical variability. While our detection rate ($\sim 0.04\%$) is lower than the 0.3%–0.4% reported by Temple et al. (2023), Guo et al. (2024) and Wang et al. (2024b), this discrepancy may result from differences in selection criteria, survey depth, and definitions of CL AGNs.

4.3. Eddington Ratios

The accretion rate during the bright state is relatively higher than that during the dim state, and the accretion rates and Eddington ratios of CL AGNs have generally been considered to be low, usually $< 1\%$ (MacLeod et al. 2019; Lyu et al. 2022; Temple et al. 2023). It has been observed that AGNs

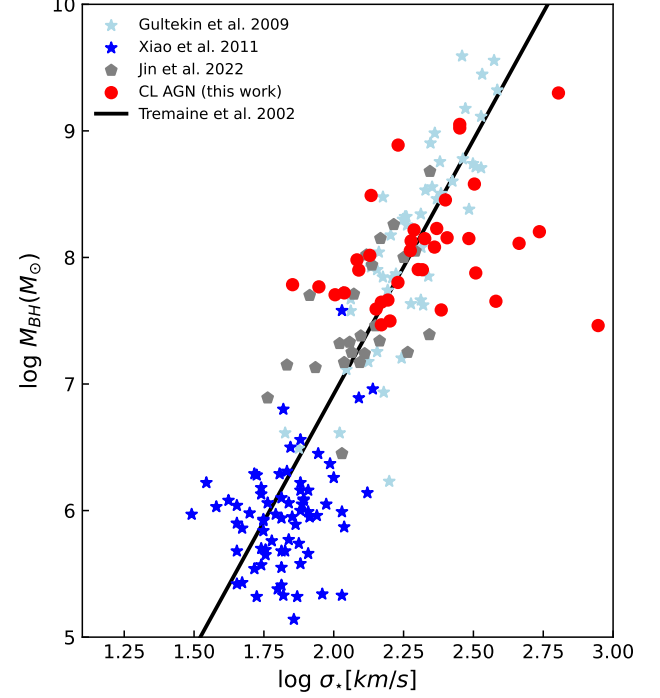


Figure 10. The $M_{\text{BH}}-\sigma_*$ relation for CL AGNs and normal galaxies. The black line in the figure represents the $M_{\text{BH}}-\sigma_*$ relation proposed by Tremaine et al. (2002). The red dots are the CL AGNs we have confirmed in this work, where σ_* is measured from the dim state spectrum, and M_{BH} is estimated from the luminosity and FWHM of the broad $H\alpha$ line in the bright state spectrum. The blue and highlighted blue stars represent NCL AGNs, and the gray pentagons are CL AGNs, originating from Xiao et al. (2011), Gu et al. (2009), and Jin et al. (2022), respectively. We found that CL AGNs also follow the general $M_{\text{BH}}-\sigma_*$ relation.

exhibiting CL behavior may undergo an evolutionary sequence where the accretion rate changes from high to low or vice versa. Therefore, studying the accretion rates of CL AGNs in different states is crucial for understanding the CL process.

Assuming that the motion of clouds in the BLR is virialized, we use the broad Balmer lines in the spectra during the bright state to estimate the central black hole mass (M_{BH}). Due to the Balmer decrement, the emission-line flux of $H\alpha$ is at least three times that of $H\beta$. Considering that the S/N of $H\alpha$ is higher than that of $H\beta$, we estimate the black hole mass using the FWHM and luminosity of the broad $H\alpha$ component according to Greene & Ho (2005), only when $H\alpha$ falls outside the wavelength coverage do we instead adopt the broad $H\beta$ component for the mass estimation:

$$\frac{M_{\text{BH}}}{M_{\odot}} = a \times 10^b \left(\frac{L}{10^{42} \text{ erg s}^{-1}} \right)^{\alpha} \left(\frac{\text{FWHM}}{10^3 \text{ km s}^{-1}} \right)^{\beta}. \quad (13)$$

We adopt the virial black hole mass scaling relations from Greene & Ho (2005), using the parameters a , b , α and β calibrated from Balmer lines. Specifically, for $H\alpha$: $a = 2$,

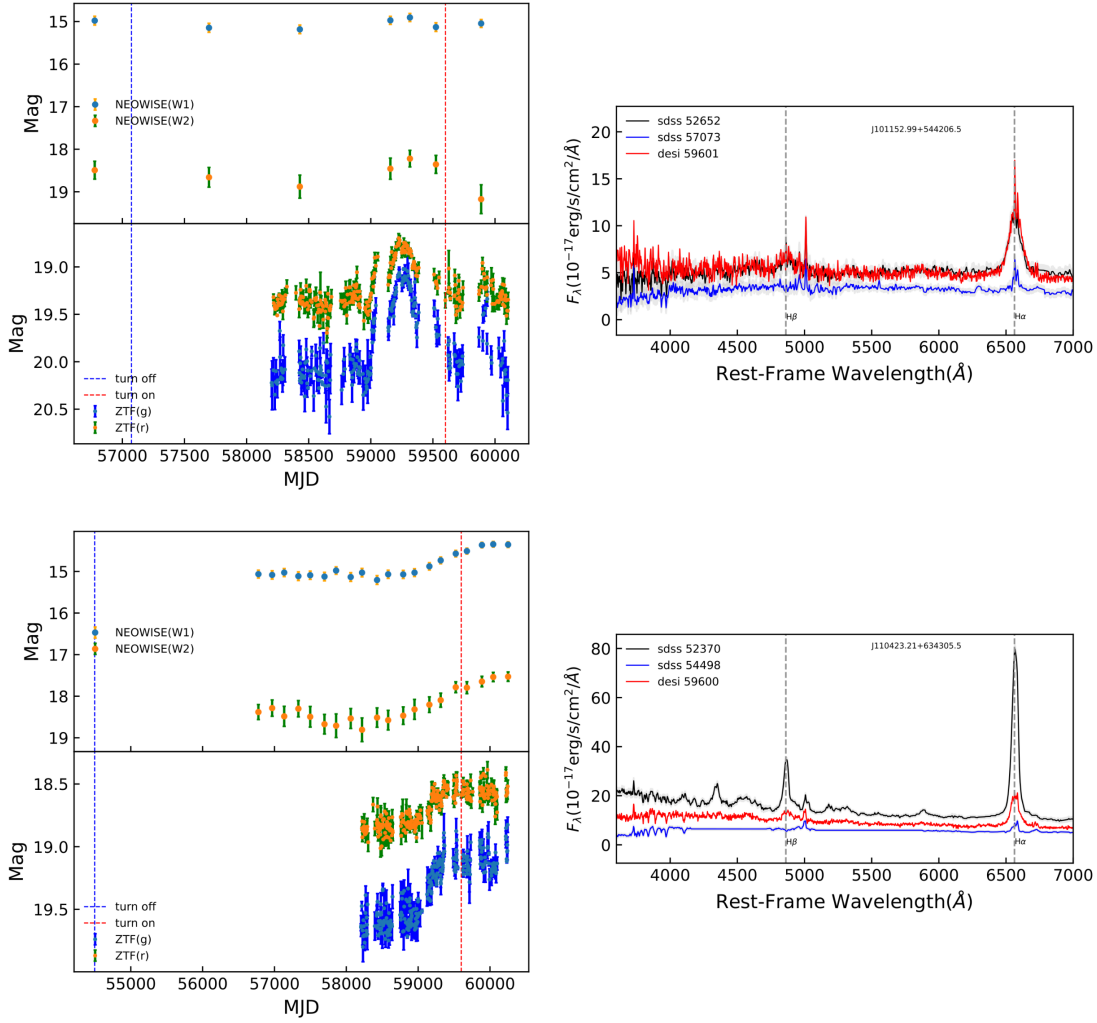


Figure 11. The light curves and spectra of the recurrent CL AGNs identified in this work. The upper-left panel shows the NIR light curve, while the lower-left panel presents the optical light curve. The blue and red dashed lines indicate the epochs of the target’s turn-off and turn-on transitions, respectively. The right panel displays multiple spectra of the target obtained from SDSS and DESI.

$b = 6.0$, $\alpha = 0.55$, and $\beta = 2.06$; and for $H\beta$: $a = 3.6$, $b = 6.0$, $\alpha = 0.56$, and $\beta = 2$. The L and FWHM are the broad $H\alpha$ ($H\beta$) line luminosity and FWHM. Then, we calculate the bolometric luminosity (L_{bol}) using the AGN continuum luminosity at 5100 Å (L_{5100}) measured from the AGN continuum component fitted using `PyQSOFit` after subtracting the host galaxy contribution, following Richards et al. (2006)

$$\lambda_{\text{Edd}} = \frac{L_{\text{bol}}}{L_{\text{Edd}}} = \frac{9.26 L_{5100} / \text{erg s}^{-1}}{1.38 \times 10^{38} M_{\text{BH}} / M_{\odot}}. \quad (14)$$

Figure 9 illustrates the distribution of CL AGNs identified in the $\lambda_{\text{Edd}}-M_{\text{BH}}$ panel. It can be observed that the λ_{Edd} of CL AGNs indeed remains at a relatively low level. Furthermore, we found that the accretion rates of the CL AGNs are significantly higher in the bright state compared to those in the dim state. This implies that the CL phenomenon might be

caused by changes in the accretion rate, which is consistent with the conclusions of previous research.

4.4. $M_{\text{BH}}-\sigma_{\star}$ Relation

CL AGNs are a remarkable subclass of AGNs that alternate between active and quiescent phases, offering a rare opportunity to probe the co-evolution of SMBHs and their host galaxies via the $M_{\text{BH}}-\sigma_{\star}$ relation. In the dim state, the AGN continuum becomes significantly fainter, enabling a more accurate measurement of the host galaxy’s stellar velocity dispersion, $\sigma_{\star}$, from the dim state spectrum (Jin et al. 2022).

Figure 10 displays the distribution of our CL AGNs in the $M_{\text{BH}}-\sigma_{\star}$ plane, along with comparison samples of normal galaxies. After excluding a small number of outliers—likely caused by low S/N spectra or residual AGN contamination in

the dim state, we find a moderate positive correlation between $\log M_{\text{BH}}$ and $\log \sigma_*$, with a Pearson correlation coefficient of $r = 0.464$ and a p -value of 2.95×10^{-2} . This trend indicates that CL AGNs generally follow the established $M_{\text{BH}}-\sigma_*$ relation, in agreement with previous findings (Shen et al. 2019; Yu et al. 2020; Jin et al. 2022). These results support the notion that CL AGNs and their host galaxies may undergo co-evolutionary processes similar to those observed in normal AGN populations.

4.5. Recurrent CL AGNs

Recurrent changing-look (RCL) AGNs refer to sources that undergo a full cycle of changing-look behavior, transitioning from a bright state to a dim state and then reverting to the bright state (or vice versa). One of the most well-known examples is Mrk 1018, which changed from a Type 1.9 to a Type 1 AGN within five years, and subsequently reverted to Type 1.9 over the following three decades (MacLeod et al. 2016). RCL AGNs represent an extremely rare subclass of CL AGNs, with only a dozen or so confirmed cases to date (Wang et al. 2024a, 2025). These sources are particularly valuable for probing the true timescales of the CL phenomenon and for exploring the physical sequence of emission-line transformations associated with state changes.

In our sample, we also identify two cases of RCL AGNs (J101152.99+544206.5 and J110423.21+634305.5), as illustrated in Figure 11. As previously mentioned, J110423.21+634305.5 had been previously confirmed as a turn-off CL AGN; however, its light curve later showed a significant brightening trend. Combined with the DESI spectrum, we confirm that it is indeed an RCL AGN. Both targets exhibit a brightening trend in their light curves during the return-on phase, indicating that photometric variability can serve as an effective tracer of AGN type transitions. The occurrence of RCL AGNs suggests that AGN accretion is not always continuous, implying that changes in AGN spectral type may be driven by fluctuations in the accretion rate.

5. Summary

In this study, we systematically analyze the optical and MIR variability of a large sample of objects at $0.1 < z < 0.75$, classified as GALAXY in SDSS DR18, using ZTF and WISE light curves. We identified 211 CL AGN candidates, and the detection rate of CL behavior is approximately 0.08%. The success rate of the method through optical and MIR variability to search CL AGNs is about 50%.

In this work, the rest-frame timescales of the CL phenomenon in our sample range from 1.7 to 18.1 yr, which is inconsistent with the obscure model. The Eddington ratios and the $M_{\text{BH}}-\sigma_*$ relation of our CL AGN sample have been estimated. Our result shows that CL behavior occurs at relatively low Eddington ratios (about 1%), and the Eddington

ratios in the bright state are significantly higher than those in the dim state. We also demonstrate that CL AGNs generally follow the same $M_{\text{BH}}-\sigma_*$ relation as quiescent galaxies, suggesting possible co-evolution between AGNs and their host galaxies. By combining the archival SDSS spectra, we identify two cases of RCL AGNs and find that the photometric light curves effectively trace the transitions in AGN spectral type.

Our work presents a large sample of CL AGN candidates, laying a foundation for future studies of the CL phenomenon. The forthcoming release of DESI DR2 will greatly aid in the identification of CL AGNs, and we anticipate that the number of known CL AGNs will increase by an order of magnitude. Additionally, the high-quality photometric data from the Legacy Survey of Space and Time will offer new opportunities for studying CL behavior and uncovering its underlying physical mechanisms.

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Data Availability

The data underlying this article will be shared on reasonable request to the corresponding author (yuanqirong@njnu.edu.cn or guowj@bao.ac.cn).

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