Accretion and Host-Galaxy Properties of 14 New “Changing-Look” Active Galactic Nuclei Identified from the SDSS-V Survey

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Abstract The widely accepted active galactic nucleus (AGN) paradigm has been recently challenged by the discovery of the so-called “changing-look” (CL) phenomenon characterized by spectral-type transitions. By comparing the SDSS-V and SDSS DR16 spectroscopic datasets, here we report the identification of 14 new CL-AGNs (redshift $z < 0.5$) exhibiting spectral-type changes on a timescale of $\sim 10$ yr. Follow-up spectroscopy was conducted with the Lick Shane 3 m and Keck 10 m telescopes for three of the objects. Detailed analysis of these spectra enables us to arrive at the following two main results. (1) By compiling a sample of 65 CL-AGNs with good measurements, we reinforce the previous claim that CL-AGNs tend to be biased against both a high Eddington ratio ($\lesssim 0.1$) and a high bolometric luminosity ($\lesssim 10^{46}$ erg s$^{-1}$). This bias suggests that the disk-wind broad-line-region model is a plausible explanation of the CL phenomenon. (2) The host galaxies of CL-AGNs tend to be dominated by intermediate stellar populations, which motivates us to propose that CL-AGNs are probably particular AGNs at a special evolutionary stage, such as a transition stage from “feast” to “famine” fueling of the supermassive black hole. In addition, with our spectra, we identify SDSS J025951.22+003744.2 as a new repeat CL narrow-line Seyfert 1 galaxy with a rapid “turn-on” timescale of $\sim 1$ yr.

Key words: galaxies: Seyfert — galaxies: nuclei — quasars: emission lines

1 INTRODUCTION

“Changing-look” active galactic nuclei (CL-AGNs), as AGNs with temporary appearance or disappearance of their broad emission lines, show a spectral transition between Type 1, intermediate type, and Type 2 within a timescale of years to decades. The CL phenomenon is still rare; thus far, with multi-epoch photometry and optical spectroscopy, only $\sim 100$ CL-AGNs have been identified (e.g., MacLeod et al. 2010, 2016, 2019; Shapovalova et al. 2010; Shappee et al. 2014; LaMassa et al. 2015; McElroy et al. 2016; Parker et al. 2016; Ruan et al. 2016; Runnoe et al. 2016; Gezari et al. 2017; Sheng et al. 2017, 2020; Kollatschny et al. 2018, 2020; Stern et al. 2018; Wang et al. 2018b, 2019, 2020a, 2022; Yang et al. 2018; Frederick et al. 2019; Guo et al. 2019; Trakhtenbrot et al. 2019; Yun et al. 2019; Ai et al. 2020; Graham et al. 2020; Green et al. 2022; Hon et al. 2022).
Recently, many studies have been carried out of CL-AGNs (e.g., Nagoshi & Iwamuro 2022; Panda & Sniegowska 2022, and references above) owing to their peculiarity. The CL phenomenon challenges the widely accepted orientation-based AGN unified model (e.g., Antonucci 1993) in which the central engine is obscured in Type 2 AGNs by the dusty torus along the line of sight to an observer, as well as the standard disk model in terms of the viscosity crisis (e.g., Lawrence 2018, and references therein). Moreover, it provides us with an ideal opportunity to investigate the host-galaxy properties of luminous AGNs. However, no significant difference between the host galaxies of CL-AGNs and non-CL-AGNs (NCL-AGNs) has been reported by a few recent studies (e.g., Charlton et al. 2019; Yu et al. 2020; Dodd et al. 2021; Liu et al. 2021; Jin et al. 2022).

At the current stage, the physical origin of CL-AGNs is still an open question. Several interpretations have been proposed, including an accelerating outflow (e.g., Shapovalova et al. 2010), a variation of the obscuration (e.g., Elitzur 2012), a tidal disruption event (e.g., Merloni et al. 2015; Blanchard et al. 2017), and an accretion-rate change (e.g., Elitzur et al. 2014; Gezari et al. 2017; Sheng et al. 2017; Yang et al. 2018; Wang et al. 2018, 2019, 2020a,b, 2022; Guo et al. 2019). There is, in fact, accumulating evidence supporting the scenario that the CL phenomenon results from a variation of accretion power of a supermassive black hole (SMBH; e.g., Feng et al. 2021a), even though the physics behind the CL phenomenon is still poorly understood (e.g., Saade et al. 2022; Ren et al. 2022).

Our current understanding of the CL phenomenon is greatly hindered by the small sample size of confirmed CL-AGNs. Enlarging samples is therefore of great importance to unveil the cause and frequency of the CL phenomenon. Fortunately, the fifth-generation Sloan Digital Sky Survey (SDSS-V; Kollmeier et al. 2017) provides us with a great opportunity to hunt for CL-AGNs via its multi-epoch spectroscopy. Identifying and characterizing CL-AGNs is, in fact, a core goal of the SDSS-V Black Hole Mapper (BHM) science program.

Here we report on a study of 14 new CL-AGNs that are identified by a systematic search with the SDSS-V/BHM dataset in combination with the SDSS Data Release 16 (DR16) spectroscopy. The paper is organized as follows. Section 2 presents the sample selection and CL-AGNs identification. Follow-up spectroscopic observations and data reduction are described in Section 3. Sections 4 and 5 present our spectral analysis and results, respectively. A discussion is given in Section 6. A $\Lambda$CDM cosmological model with parameters $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$ is adopted throughout.

2 SAMPLE SELECTION AND CL-AGNS IDENTIFICATION

2.1 SDSS-V Survey

SDSS-V is an all-sky, multi-epoch spectroscopic survey of over six million objects (Kollmeier et al. 2017). It consists of three primary survey programs: Milky Way Mapper (MWM), Black Hole Mapper (BHM), and Local Volume Mapper (LVM). The main purpose of the BHM is to study AGNs over long time intervals to measure black hole masses and discover CL quasars (CL-QSOs), and to optically characterize eROSITA X-ray sources. The BHM will provide multi-epoch optical ($\lambda = 360$–1000 nm) spectra of $\sim 25,000$ QSOs with $i < 19$ mag at a spectral resolution of $R = \lambda/\Delta\lambda \approx 2000$ (Smee et al. 2013) that is comparable to that of BOSS. The number of epochs ranges from 3 to 13. In order to cover the whole sky, dual-hemisphere observations are performed in a parallel way with two 2.5 m telescopes. One is the 2.5 m Sloan Foundation Telescope (Gunn et al. 2006) at Apache Point Observatory (APO) in New Mexico, and the other is the 2.5 m du Pont telescope of the Carnegie Observatories at Las Campanas Observatory (LCO) in Chile (Bowen & Vaughan 1973).

2.2 Crossmatch of SDSS-V/BHM and SDSS DR16

We first crossmatch the SDSS-V/BHM dataset v6.0.4 (October 11, 2021) with the SDSS DR16 QSO catalog (Lyke et al. 2020, and references therein) by their celestial coordinates within a crossmatch-
For each of the 1270 QSOs, a set of differential spectra is created from a pair of SDSS-V and DR16 spectra, and is used to search for new CL-AGNs. Each differential spectrum is created as follows. Both SDSS-V and DR16 spectra are first transformed to the rest frame according to the redshift reported in the SDSS DR16 catalog, along with a correction of Galactic extinction by assuming an $R_V = 3.1$ extinction law of the Milky Way (Cardelli et al. 1989). The extinction values are derived from the Galactic reddening map of Schlegel, Finkbeiner, & Davis (1998). We note that the redshifts reported in the SDSS-V dataset are found to be systematically larger than the DR16 values. As shown in Figure 1, the distribution of $\Delta z = z_{\text{SDSS-V}} - z_{\text{DR16}}$ has an average of $\langle \Delta z \rangle = 0.000908$ (corresponding to a velocity of 270 km s$^{-1}$) and a standard deviation of 0.001766. In the rest frame, this small difference can indeed result in a significant mismatch in wavelength for strong, narrow emission lines, especially the [O III] $\lambda\lambda 4959, 5007$ doublet. After scaling the flux level by the [O III] $\lambda 5007$ line flux (see Sec. 4.2 for details), a differential spectrum is built by $\Delta f_\lambda = f_{\lambda,\text{SDSS-V}} - f_{\lambda,\text{DR16}}$.

With the differential spectra, we identify 14 new CL-AGNs by examining by eye the change of the Balmer-line profiles in individual objects. We emphasize that there is only one SDSS DR16 spectrum for each of the 14 new CL-AGNs. Figures 2 and 3 present not only a comparison between the SDSS-V and DR16 spectra, but also the differential spectra. In addition, our examination indicates that there are 130 spectral pairs showing significant Balmer line profile variation, although they are beyond the scope of the current study.
Fig. 2 A comparison of the multi-epoch rest-frame spectra for 8 of the 14 new CL-AGNs. In each panel, the SDSS-V and SDSS DR16 spectra are denoted by the red and blue lines, respectively. The bottom black lines are the differential spectrum, when the SDSS DR16 spectrum is used as a reference. Before the subtraction, the two spectra are scaled in flux level according to their [O III] $\lambda$5007 line fluxes. The spectra are shifted vertically for clarity.

3 FOLLOW-UP SPECTROSCOPY AND DATA REDUCTION

For three of the newly identified CL-AGNs, we conducted follow-up spectroscopy to confirm the identification with enhanced spectral quality, and to search for variability on short timescales of $\sim$ 1 yr.

3.1 Lick/Shane 3 m Spectroscopy

We obtained long-slit spectra of SDSS J011536.11+003352.4 with the Kast double spectrograph (Miller & Stone 1993) mounted on the 3 m Shane telescope at Lick Observatory on 2022 February 05 (UT dates
Grism 600/4310 was employed on the blue side and grating 300/7500 on the red side, providing respective wavelength resolutions of \( \sim 5 \) Å and \( \sim 12 \) Å and a total wavelength range of 3600–10,700 Å. The 2′′-wide slit was aligned near the parallactic angle (Filippenko 1982) to minimize differential light losses caused by atmospheric dispersion, and the exposure time was 1500 s. The spectrum was flux calibrated with observations of Kitt Peak National Observatory standard stars (Massey et al. 1988).

The one-dimensional (1D) spectrum was extracted from the raw image by using the IRAF package and standard procedures, including bias subtraction and flat-field correction. The 1D spectrum was then calibrated in wavelength and in flux with spectra of the corresponding comparison lamp and standard stars. The accuracy of the wavelength calibration is better than 1 Å. The telluric A-band (7600–7630 Å) and B-band (around 6860 Å) absorption produced by atmospheric O\(_2\) molecules were removed from both spectra by using the observation of the standard star.

The calibrated spectrum was then corrected for the Galactic extinction of \( E(B-V) = 0.01856 \) mag (Schlegel et al. 1998) taken from NED. The correction was applied by assuming the \( R_V = 3.1 \) extinction law of our Galaxy (Cardelli et al. 1989). The spectrum was then transformed to the rest frame based on the redshift given in SDSS DR16, and compared with the SDSS-V spectrum in Figure 4.

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2 IRAF is distributed by NOAO, which is operated by AURA, Inc., under cooperative agreement with the U.S. National Science Foundation (NSF).
Fig. 4 The rest-frame spectra of SDSS J011536.11+003352.4 taken by our follow-up spectroscopy in 2022 compared with the SDSS-V spectrum taken in 2020 (blue curve). The spectra obtained by the Lick/Shane 3 m telescope and the Keck-I 10 m telescope are shown by the green and red curves, respectively. Using the SDSS-V spectrum as a reference, the Keck differential spectrum created by the method used in Figures 2 and 3 is shown with the bottom black curve. The spectra are shifted vertically for clarity.

3.2 Keck Spectroscopy

Follow-up spectra of three of the 14 new CL-AGNs were obtained with the Keck I 10 m telescope and the Low Resolution Imaging Spectrometer (LRIS; Oke et al. 1995) on January 31, 2022 (SDSS J012025.44+142727.9 and SDSS J025951.22+003744.2) and July 01, 2022 (SDSS J011536.11+003352.4). With the 5600 Å dichroic, we used the 600/4000 blue grism (dispersion 0.63 Å pixel$^{-1}$) and the 400/8500 red grating (dispersion 1.20 Å pixel$^{-1}$), covering $\sim$ 3150–10,270 Å. A 1′′-wide slit aligned near the parallactic angle was used during the observations. The
exposure times were 900 s for SDSS J011536.11+003352.4 and SDSS J012025.44+142727.9, and 600 s for SDSS J025951.22+003744.2. The raw data were reduced by using the LPipe pipeline (Perley 2019), which performs a completely automated, end-to-end reduction of LRIS spectra.

Through the methods described above, including Galactic extinction and relativity corrections, the rest-frame spectra were obtained from the calibrated 1D spectra and displayed in Figures 4 and 5. Compared to the SDSS-V spectrum, the Keck spectra of both SDSS J011536.11+003352.4 and SDSS J012025.44+142727.9 with a higher SNR (especially at the red end) allow us to confirm the CL phenomenon in the objects. In Figure 4, the differential spectrum created by the method described in Section 2.3 additionally shows a continuous strengthening of the Hα broad-line emission in SDSS J011536.11+003352.4, which means the continuous “turn-on” process in the object has been captured by the SDSS-V survey and our follow-up observations.

Our Keck spectrum shows that SDSS J025951.22+003744.2 is quite interesting. Compared to the SDSS-V spectrum at the “turn-off” state, the object comes back to the “turn-on” state with a timescale of only ∼ 1 yr. We will return to its implications in Section 6.

4 SPECTRAL ANALYSIS AND MODELING

In order to quantify the CL phenomena identified in the 14 new CL-AGNs and to reveal the underlying physics, spectral analysis was performed by following our previous studies (e.g., Wang et al. 2019, and references therein).

4.1 AGN Continuum and Stellar Feature Removal

Initially, to isolate the emission-line spectrum, we model the continuum of each of the spectra by a linear combination of the following components: (1) an AGN power-law continuum; (2) a template of both high-order Balmer emission lines and a Balmer continuum from the broad-line region (BLR); (3) a template of both the optical and ultraviolet (UV) FeII complex; (4) a host-galaxy component built
from a linear combination of the first seven eigenspectra that are extracted from the standard single stellar population spectral library developed by Bruzual & Charlot (2003); and (5) an intrinsic extinction due to the host galaxy described by a Galactic extinction curve with $R_V = 3.1$. Note that not all the components are necessary to reproduce the continuum in an individual spectrum owing to its limited SNR (see figures in the electronic material).

We use the empirical optical FeII template provided by Veron-Cetty et al. (2004) and the theoretical template by Bruhweiler & Verner (2008) to model the optical and UV FeII complex, respectively. The adopted optical FeII template includes both broad and narrow components of the FeII emission. Bruhweiler & Verner (2008) calculated a grid of UV FeII emission. The predicted spectrum giving the best fit to the observed I Zw 1 spectrum is used in the current fitting, which is calculated for log[$n_H/(cm^{-3})] = 11.0$, log[$\Phi_B/(cm^{-2} s^{-1})] = 20.5$, $\xi/(1 km s^{-1}) = 20$, and 830 energy levels. In advance of the fitting, the line width of both templates is fixed to be that of the broad component of H$\beta$ (or H$\alpha$) by convolving with a Gaussian profile, which is determined by our line-profile modeling (see below).

The emission from a partially optically thick cloud with an electron temperature of $T_e = 1.0 \times 10^4$ K is adopted to model the Balmer continuum $f^{BC}_\lambda$ by following Dietrich et al. (2002; see also Malkan & Sargent 1982):

$$f^{BC}_\lambda = f^{BE}_\lambda B_\lambda(T_e)(1 - e^{-\tau_\lambda}) \lambda \leq \lambda_{BE}.$$  

(1)

where $f^{BC}_\lambda$ is the continuum flux at the Balmer edge at $\lambda_{BE} = 3646$ Å, $B_\lambda(T_e)$ is the Planck function, and $\tau_\lambda$ is the optical depth at wavelength $\lambda$, which is related to the one at the Balmer edge as $\tau_\lambda = \tau_{BE}(\lambda/\lambda_{BE})^3$. A typical value of $\tau_{BE} = 0.5$ is adopted in our continuum modeling.

We model the high-order Balmer lines (i.e., H7—H50) by the Case B recombination model with $T_e = 1.5 \times 10^4$ K and an electron density of $n_e = 10^{7-8}$ cm$^{-3}$ (Storey & Hummer 1995). The widths of these high-order Balmer lines are, again, determined in advance according to the line-profile modeling of the H$\beta$ (or H$\alpha$) broad emission (see below).

For each spectrum, a $\chi^2$ minimization is performed iteratively over the whole spectroscopic wavelength range, except for the regions with known strong emission lines, such as low-order Balmer lines (both narrow and broad components), [S II] $\lambda\lambda$6716, 6731, [N II] $\lambda\lambda$6548, 6583, [O I] $\lambda$6300, [O III] $\lambda\lambda$4959, 5007, [O II] $\lambda\lambda$3726, 3729, [Ne III] $\lambda$3869, [Ne V] $\lambda$3426, and Mg II $\lambda$2800. In the minimization, the velocity dispersion of the stellar component is a free parameter for the Keck, SDSS-V, and DR16 spectra, and is fixed in advance for the Shane/Kast spectrum, because the observed absorption features are dominated by the instrumental profile. As an example, the subtraction of the AGN continuum and starlight component is illustrated in the left panels of Figure 6 for SDSS J025951.22+003744.2. As shown in the left-middle panel, complicated modeling of the continuum is not necessary for this object because of its weak and flat continuum at that epoch. The continuum is instead removed by a local linear function determined by the continuum adjacent to the emission lines. A full set of the continuum subtraction of the 14 new CL-AGNs is presented in the electronic material.

### 4.2 Line-Profile Modeling

After removing the underlying starlight component and AGN continuum, a linear combination of a set of Gaussian profiles is adopted to model the emission-line profiles in the H$\alpha$ and H$\beta$ regions in each of the spectra by the SPECFIT task (Kriss 1994) in IRAF. In the modeling, each of the Balmer lines is reproduced by a linear combination of a narrow component and one or two broad components. The line-flux ratios of the [O III] $\lambda\lambda$4959, 5007 and [N II] $\lambda\lambda$6548, 6583 doublets are fixed to their theoretical values of 1:3 (e.g., Dimitrijevic et al. 2007). In addition to a narrow component, a blueshifted broad component is necessary for reproducing the [O III] $\lambda\lambda$4959, 5007 line profiles in a fraction of spectra (e.g., Boroson 2005; Zhang et al. 2013; Harrison et al. 2014; Woo et al. 2017; Wang et al. 2011, 2018).

As an example, the line-profile modelings are illustrated in the middle and right columns in Figure 6 for the H$\beta$ and H$\alpha$ regions. A full set of the line-profile modelings of the 14 new CL-AGNs can again be found in the electronic material.
5 ANALYSIS AND RESULTS

The results of our spectral analysis are given in Table 1. The redshift and UT observation date are listed in Columns (2) and (3), respectively. Columns (4), (5), and (6) list the measured line fluxes of total [O III] $\lambda$5007, broad H$\beta$, and broad H$\alpha$ emission. The widths of the broad H$\beta$ and H$\alpha$ are shown in Columns (7) and (9), respectively. In a few cases, the H$\alpha$ or H$\beta$ broad emission has to be reproduced by two or three Gaussian functions. The full width at half-maximum intensity (FWHM) of the integrated broad-line emission is measured from a residual profile that is obtained by subtracting the modeled narrow component from the observed profile. The bulk relative velocity shifts $\Delta v$ are listed in Columns (8) and (10) for the broad H$\beta$ and H$\alpha$, respectively. $\Delta v$ is calculated as $\Delta v = c \Delta \lambda / \lambda_0$, where $\lambda_0$ and $\Delta \lambda$ are (respectively) the rest-frame wavelength in vacuum and the wavelength shift of the line relative to the narrow component. In addition, the corresponding CL phenomenon status (“on” or “off”) is shown in Column (14). The “turn-off” state corresponds to either undetectable or marginally detectable broad H$\beta$ emission, and the “turn-on” state to a state with easily evident broad H$\beta$ emission.

All of the uncertainties reported in Table 1 correspond to the $1\sigma$ significance level and include only the uncertainties caused by the fitting, rather than the removal of the stellar continuum.

Table 1 Results of Line-Profile Modeling and Analysis

| UT Date | Redshift | Widths of Broad Components | Emission Line Fluxes | FWHM of Broad Emission Lines | Bulk Relative Velocity Shifts |
|---------|----------|---------------------------|---------------------|-----------------------------|------------------------------|
| J020649.47-041452.7 | 0.1389927 | 2008-12-22 | 64 | 4 | 1.12 | 0.62 |
| J140515.59+542457.9 | 0.0832624 | 2003-03-07 | 4 | 0 | 0.10 | 0.62 |
| J201945.60-003822.7 | 0.08903628 | 2001-09-20 | 2 | 1 | 0.10 | 0.62 |
| J220946.60-003822.7 | 0.08903628 | 2001-09-20 | 2 | 1 | 0.10 | 0.62 |
| J010646.04+130039.8 | 0.367734 | 2006-12-22 | 1.12 | 1 | 0.10 | 0.62 |
| J014051.70+205326.9 | 0.0852624 | 2003-03-07 | 4 | 0 | 0.10 | 0.62 |
| J020649.47-041452.7 | 0.1389927 | 2008-12-22 | 64 | 4 | 1.12 | 0.62 |

5.1 Estimation of Black Hole Mass and Eddington Ratio

Thanks to the well-established calibrated relationships based on AGN single-epoch spectra (e.g., Kaspi et al. 2000, 2005; Wu et al. 2006; Peterson & Bentz 2006; Marziani & Sulentic 2012; Du et al. 2014, 2015; Peterson 2014; Wang et al. 2014), the black hole virial mass ($M_{BH}$) and Eddington ratio ($L_{bol}$/$L_{Edd}$, where $L_{Edd} = 1.26 \times 10^{38} (M_{BH}/M_\odot) \text{ erg s}^{-1}$ is the Eddington luminosity) can be estimated in terms of the modeled H$\alpha$ broad emission line through the traditional method described by Wang et al. (2020a).

Briefly speaking, $M_{BH}$ can be estimated by the calibration (Greene & Ho 2007)

$$M_{BH} = 3.0 \times 10^6 \left( \frac{L_{H\alpha}}{10^{42} \text{ erg s}^{-1}} \right)^{0.45} \left( \frac{\text{FWHM}_{H\alpha}}{1000 \text{ km s}^{-1}} \right)^{2.06} M_\odot$$

In a few objects, their weak broad H$\beta$ emission line, in fact, suggests a “dim state” rather than a classical “turn-off” state that is defined by the disappearance of broad H$\beta$. In these cases, we use the “turn-off” term only for convenience in later statistical and comparison studies.
and $L_{\text{bol}}/L_{\text{Edd}}$ through a bolometric correction of $L_{\text{bol}} = 9\lambda L_\lambda(5100 \text{ Å})$ (e.g., Kaspi et al. 2000), where (Greene & Ho 2005)

$$\lambda L_\lambda(5100 \text{ Å}) = 2.4 \times 10^{43} \left(\frac{L_{H\alpha}}{10^{42} \text{ erg s}^{-1}}\right)^{0.86} \text{ erg s}^{-1}. \quad (3)$$

In deriving intrinsic broad $H\alpha$ line luminosity $L_{H\alpha}$ obtained at different epochs, the measured broad $H\alpha$ line fluxes of individual object are first scaled by a factor determined by equaling the total [O III] $\lambda 5007$ line flux to that of the SDSS DR16 spectrum. The intrinsic extinction is then corrected from the narrow-line flux ratio $H\alpha/H\beta$ by assuming the Balmer decrement of standard Case B recombination and a Galactic extinction curve with $R_V = 3.1$. In the current study, the used $H\alpha/H\beta$ flux ratio in an individual object is determined by averaging the values measured from the corresponding multi-epoch spectra. Columns (11) and (12) in Table 1 list the estimated $M_{\text{BH}}$ and $L_{\text{bol}}/L_{\text{Edd}}$, respectively. Being dominated by the calibration scatters, the uncertainties of $M_{\text{BH}}$ and $L_{\text{bol}}/L_{\text{Edd}}$ are $\sim 0.2$ dex and $\sim 65\%$ (or 0.28 dex), respectively.

### 5.2 Stellar Population of the Hosts of the New CL-AGNs

It is well known that both the 4000 Å break [$D_n(4000)$] and the equivalent width (EW) of the $H\delta$ absorption ($H\delta_A$) are widely used as reliable age indicators in AGN host galaxies until a few Gyr after a starburst (e.g., Kauffmann et al. 2003; Heckman et al. 2004; Kewley et al. 2006; Kauffmann & Heckman 2009; Wild et al. 2010; Wang & Wei 2008, 2010; Wang et al. 2013; Wang 2015), although both indices are sensitive to metallicity in very old stellar populations. The $D_n(4000)$ is defined as (Balogh et al. 1999; Bruzual 1983)

$$D_n(4000) = \frac{\int_{4100}^{4999} f_\lambda d\lambda}{\int_{3950}^{3850} f_\lambda d\lambda}. \quad (4)$$

We measure the value of $D_n(4000)$ from the modeled starlight in the “turn-off” spectrum of individual objects, except for SDSS 025951.22+003744.2 and SDSS 081127.88+222045.3 owing to significant contamination by the AGN continuum. The measured $D_n(4000)$ are presented in Column (13) of Table 1. Combining the uncertainties due to both measurements on duplicate observations (Wang et al. 2011) and AGN’s continuum removal (Wang 2015), the typical uncertainty of $D_n(4000)$ is estimated to be $\sim 0.04$.

### 5.3 Statistics

#### 5.3.1 SMBH Accretion

Figure 7 shows the distributions of the CL-AGNs on the $L_{\text{bol}}$ vs. $M_{\text{BH}}$ (left panels) and $L_{\text{bol}}$ vs. $L_{\text{bol}}/L_{\text{Edd}}$ (right panels) diagrams, after combining the new 14 CL-AGNs identified in this study and CL-AGNs compiled from the literature and requiring detailed measurements of both their on and off states$^4$. The sample shown in the figure contains a total of 65 CL-AGNs with $z < 0.5$. The comparison samples shown by different symbols and colors are (1) the SDSS DR7 quasars with $z < 0.5$ (Shen et al. 2011), (2) the SDSS DR3 so-called “narrow-line Seyfert 1 galaxies” (NLS1s) given by Zhou et al. (2006), (3) the Swift/BAT AGN sample with a spectral type classification by Winter et al. (2012), and (4) the SDSS intermediate-type Seyfert galaxies studied by Wang (2015). In the figure, the top two panels correspond to the “turn-on” state, and the bottom two panels to the “turn-off” state.

One can see from the figure that, with a large sample of 65 CL-AGNs, the current study reinforces the result that CL-AGNs tend to be biased against both high $L_{\text{bol}}$ and high $L_{\text{bol}}/L_{\text{Edd}}$ compared to the whole AGN population (e.g., MacLeod et al. 2019; Wang et al. 2019; Frederick et al. 2019; Jin et al. 2022).

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$^4$ The data are taken from MacLeod et al. (2019), Yang et al. (2018), Ruan et al. (2016), LaMassa et al. (2015), Wang et al. (2018, 2019, 2020, 2021), Runnoe et al. (2015), and Jin et al. (2022).
2022). Specifically speaking, we have $L_{\text{bol}} < 10^{46}$ erg s$^{-1}$ and $L_{\text{bol}}/L_{\text{Edd}} < 0.1$ for the CL-AGNs at their “turn-on” states.

5.3.2 Host Galaxies

The measured $D_n(4000)$ index ranges from 1.27 to 1.95, with average and median values of 1.54 and 1.50, respectively. The corresponding standard deviation is 0.21. We argue that the $D_n(4000)$ value reported in Table 1 is likely underestimated in a fraction of cases, because the contamination due to the very weak underlying AGN continuum is neglected in our continuum removal, although the level of the underestimation is typically slight (e.g., Figure 2 of Wang 2015).

The measurements of $D_n(4000)$ suggest that the CL-AGNs identified in the current study tend to be associated with an intermediate-age stellar population, which roughly agrees with the results recently reported by Liu et al. (2021) and Jin et al. (2022). A value of $D_n(4000) = 1.4-1.6$ is, in fact, usually adopted as a threshold for separating young and old stellar populations (e.g., Kauffmann et al. 2003). Liu et al. (2021) point out that local CL-AGNs tend to reside in galaxies located in the “green valley,” rather than in blue host galaxies, where the average and median $D_n(4000)$ values are 1.47 and 1.46, respectively. Again, the corresponding standard deviation is 0.21. In addition, based on stellar-population synthesis on 26 “turn-off” CL-AGNs, Jin et al. (2022) recently proposed that CL-AGNs are mainly characterized by intermediate-age stellar populations.

6 DISCUSSION

By examining the SDSS-V/BHM dataset along with our follow-up spectroscopy, we identified 14 new CL-AGNs whose spectral types have changed during past $\sim 10$ yr from a parent sample of 1550 QSOs with $z < 0.5$. Based on the blind SDSS multi-epoch spectral survey, this number suggests that on a timescale of $\sim 10$ yr the total CL-AGN fraction is $\approx 0.9\%$ at $z < 0.5$. This value is much larger than the previous claims of 0.007–0.11\% (e.g., Yang et al. 2018; Yu et al. 2020), probably because we focus on low-redshift objects for which the data typically have higher SNR.

Subsequent spectral analysis on the new CL-AGNs enables us to reinforce the previous claims that CL-AGNs tend to be biased against both high $L_{\text{bol}}$ and high $L_{\text{bol}}/L_{\text{Edd}}$, and toward an intermediate-age stellar population.

6.1 Physical Origin of the CL Phenomenon

The mid-infrared (MIR) light curves of the 14 new CL-AGNs are shown in Figure 8, in which the $w1 (3.4\mu m)$ and $w2 (4.6\mu m)$ bands values are taken from the Wide-field Infrared Survey Explorer (WISE and NEOWISE-R; Wright et al. 2010; Mainzer et al. 2014). Although the epochs of the SDSS DR16 spectra are not covered by the WISE survey, one can see that the CL status revealed by the SDSS-V spectra is generally related to the $w1$ and $w2$ brightness: a “turn-on” status corresponds to an MIR brightening, and a “turn-off” status to an MIR dimming. This tendency is consistent with the expectation of the accretion-rate enhancement scenario of the CL phenomenon (e.g., Sheng et al. 2017; Stern et al. 2018; Wang et al. 2019, 2020, 2021; Yang et al. 2018).

After excluding the obscuring effect through their MIR variation\(5\), the fact that CL-AGNs tend to be biased against high $L_{\text{bol}}$ and high $L_{\text{bol}}/L_{\text{Edd}}$ motivates some authors to argue that the CL phenomenon could be understood by the disk-wind BLR models previously proposed by Elitzur & Ho (2009) and Nicastro (2000). On the one hand, in the Elitzur & Ho (2009) model, because the mass-outflow rate scales with $L$ as $L^{1/4}$, an observable BLR cannot be sustained below a certain luminosity, $L \approx 5 \times 10^{39} (M_{\text{BH}}/10^7 M_\odot)^{2/3} \text{erg s}^{-1}$, which corresponds to a critical value of $L_{\text{bol}}/L_{\text{Edd}} \approx 10^{-6}$ (Elitzur & Shlosman 2006).

\(5\) In fact, the spectropolarimetry performed by Hutsemekers et al. (2019) shows that CL-AGNs in the “turn-off” state typically have polarization below 1%, implying that the clumpy obscuration scenario is unlikely to explain the disappearance of the broad emission lines.
On the other hand, a much higher critical value of $L_{bol}/L_{Edd} \approx 2-3 \times 10^{-3}$ has been proposed for $M_{BH}$ within a range of $10^{7-8} M_\odot$ by Nicastro (2000), in which the appearance or disappearance of the BLR depends on a critical radius of the accretion disk where the power deposited into the vertical outflow is the maximum value. One would argue against this scenario by being aware of the fact that, as shown in Figure 7 and Table 1, the calculated $L_{bol}/L_{Edd}$ at the “turn-off” state is usually higher than the above critical value by an order of magnitude. This inconsistency can be easily understood since the reported $L_{bol}/L_{Edd}$ at the “turn-off” state is usually estimated from the weakened broad Balmer emission lines. In fact, our X-ray observation of the CL-AGN UGC 3223 shows that its $L_{bol}/L_{Edd}$ was as low as $\sim 2 \times 10^{-4}$ when the broad Balmer emission lines disappeared completely (Wang et al. 2020b; see also Ai et al. (2020) and Wang et al. (2022) for other cases with $L_{bol}/L_{Edd}$ inferred from X-rays). In the model, a thermally unstable radiation-pressure-dominated disk region is required for the existence of a BLR, which implies that the thermal timescale is typical of the CL phenomenon. This timescale is, in fact, able to account for the observed short variations of order one to a few years (see Section 6.3.3).

With increasing cases of identified CL-AGNs, a few other possible models have been proposed recently to understand the CL phenomenon, especially the repeat CL phenomenon (for example, SDSS J025951.22+003744.2 in the current study). Pan et al. (2021) show that the observed repeat CL-AGNs could be explained by reducing the disk burst period by including the effect of a large-scale magnetic field (e.g., Dexter & Begelman 2009) in the disk-instability model suggested by Sniegowska et al. (2020). Compared to the standard thin accretion disk, Feng et al. (2021b) propose that the short timescale of the CL phenomenon could be understood in terms of a magnetic accretion disk-outflow mode, in which the inflow timescale is significantly reduced by magnetic outflows. The theoretical study by Wang & Bon (2020) suggests that CL-AGNs could be triggered by close binaries of SMBHs with a high eccentricity. A tidal torque on the mini-disk of each SMBH can either squeeze or expand the disk, resulting in a spectral type transition cycle determined by the orbital period. The authors argue that this scenario is able to explain the highly asymmetric and double-peaked broad-line profiles observed in some CL-AGNs (e.g., Storchi-Bergmann et al. 2017).

### 6.2 Implication from the Intermediate-Age Stellar Populations

Although no significant difference between the host galaxies of CL-AGNs and NCL-AGNs has been reported in recent years (e.g., Charlton et al. 2019; Yu et al. 2020; Dodd et al. 2021; Liu et al. 2021; Jin et al. 2022), we point out that the stellar population of CL-AGNs tends to be dominated by intermediate-age stellar populations (see also Liu et al. 2021; Jin et al. 2022; Dodd et al. 2021).

By analyzing the distribution of $L_{bol}/L_{Edd}$ as a function of $M_{BH}$ and properties of the host galaxies for a large sample of local Seyfert 2 galaxies surveyed by SDSS, Kauffmann & Heckman (2009) proposed that there are two distinct regimes of SMBH accretion. On the one hand, the growth of SMBHs associated with a young central stellar population and significant star formation is less dependent on the central stellar population of the galaxy. The plentiful cold gas supply can guarantee a steady inward fueling flow of cold gas (i.e., “feast fueling”). One the other hand, for the SMBHs associated with an old central stellar population, the time-averaged mass growth rate is proportional to the mass of bulge of the host galaxy (i.e., “famine fueling”). This dependence could be understood if, when the cold gas in a reservoir is consumed, the SMBHs are fed by slow stellar winds generated by evolved stars or by inward mass transport triggered by either minor mergers or multiple collisions of cold-gas clumps in the intergalactic medium (e.g., Kauffmann & Heckman 2009; Davies et al. 2007, 2014; Pizzolato & Soker 2005; Gaspari et al. 2013).

Having an association with intermediate-age stellar populations, we argue that CL-AGNs are particular AGNs at a special evolutionary stage. Kauffmann & Heckman (2009), in fact, indicate that a transition between the aforementioned two SMBH accretion regimes occurs at $D_n(4000) = 1.5-1.8$, comparable to the measured average value and standard deviation of $D_n(4000)$ of the CL-AGNs.

Figure 9 marks the 12 newly identified CL-AGNs with available $D_n(4000)$ values on the $D_n(4000) - L_{bol}/L_{Edd}$ diagram, showing a strong relationship between $L_{bol}/L_{Edd}$ and $D_n(4000)$ for the local
NCL-AGNs studied by Wang (2015), in which $L_{\text{bol}}/L_{\text{Edd}}$ is estimated from their broad Hα line emission. The relationship suggests a coevolution between SMBH growth and host galaxy wherein the SMBH resides: $L_{\text{bol}}/L_{\text{Edd}}$ decreases as the young stellar population continuously ages (e.g., Kewley et al. 2006; Wang et al. 2006, 2013; Wang & Wei 2008, 2010; Wang 2015). For each of the new CL-AGNs identified in this study, the values of $L_{\text{bol}}/L_{\text{Edd}}$ of both “turn-on” and “turn-off” states, along with the average values, are marked by different symbols. One can see from the figure that the CL-AGNs at the “turn-on” state roughly follow the NCL-AGNs, except for an enhanced $L_{\text{bol}}/L_{\text{Edd}}$ at a given $D_n(4000)$. This enhancement is not hard to understand, because $L_{\text{bol}}/L_{\text{Edd}} \propto L^{0.4}$ according to Equations (2) and (3).

Given the inferred stellar population and the concept of coevolution between SMBH and host galaxy (see Heckman & Best 2014, for a review), we here propose that CL-AGNs are probably at a transition between the fast and famine SMBH fueling stages that are profiled by Kauffmann & Heckman (2009). At the transition, the cold gas in the reservoir has been almost exhausted by steady inward fueling flow; thereafter, episodic fueling is expected when the fueling is contributed by slow stellar winds of evolved stars, especially those in the asymptotic branch, or by chaotic accretion (e.g., King & Pringle 2006, 2007). The proposed particular evolutionary stage of CL-AGNs is supported by recent other studies. On the one hand, from the view of host galaxies, besides the studies of direct stellar populations mentioned above, Dodd et al. (2021) indicate that CL-AGNs tend to reside in high-density pseudobulges located in the so-called “green valley” that is believed to be a transition region between active star-forming galaxies and inactive elliptical galaxies owing to the quenching of AGNs. On the other hand, from the view of SMBH accretion, the mid-infrared Eddington ratio of CL-AGNs is found to be in accord with a transition between a Shakura-Sunyaev disk (Shakura & Sunyaev 1973) and radiatively inefficient accretion flow (Lyu et al. 2022). By comparing CL-AGNs and different types of AGNs, Liu et al. (2022) suggest that CL-AGNs are possible at special evolutionary stage with $L_{\text{bol}}/L_{\text{Edd}} \approx 0.1$ since they show a transition between the positive and negative $\Gamma - L_X/L_{\text{Edd}}$ correlation in the CL phenomenon.

### 6.3 SDSS J025951.22+003744.2

#### 6.3.1 A Repeat CL-AGN with an NLS1-Like Spectrum

At its “turn-on” state, SDSS J025951.22+003744.2 shows a typical blue continuum, small Hβ line width (FWHM(Hβ) = 1770 ± 100 km s$^{-1}$), large $R_{\text{FeII}} = \text{FeII}/H\beta = 0.44$, small $M_{\text{BH}} = 4.7 \times 10^7 M_\odot$, and high $L/L_{\text{Edd}} = 0.6$. Among the 14 new CL-AGNs, this object is the only NLS1, with relatively narrow broad-Balmer emission (FWHM(Hβ) ≤ 2000 km s$^{-1}$) and strong FeII-complex emission. Owing to their small $M_{\text{BH}}$ and high $L/L_{\text{Edd}}$, NLS1s are believed to be “young” AGNs at a phase of rapid BH growth (e.g., Boroson 2002; Xu et al. 2012; Grupe 2004; see Komossa 2008 for a review). The “young” AGN scenario is actually consistent with the special properties of their host galaxies (e.g., Mathur 2000). There is evidence supporting that NLS1s are associated with not only intense circumnuclear star formation (e.g., Sani et al. 2010; Scharwachter et al. 2017), but also pseudo-bulges (e.g., Orban de Xivry et al. 2011; Mathur et al. 2012) deviating from the usual $M_{\text{BH}} - \sigma$ relations (Kormendy et al. 2011), although the deviation is eliminated if the width of the [SII] $\lambda\lambda 6716, 6731$ emission lines is used as a proxy for the bulge stellar velocity dispersion (Komossa & Xu 2007). The youth of NLS1s is additionally supported by the fact that they are found to reside in less-dense environments than broad-line Seyfert 1 galaxies (e.g., Jarvela et al. 2017).

CL-NLS1s are quite rare at the current time (Oknyansky et al. 2018). To our knowledge, only four CL-NLS1s have been reported previously. MacLeod et al. (2019) identified SDSS J123359.12+084211.5 as a CL-NLS1 with large $L/L_{\text{Edd}}$ and a remarkable change in both Balmer and FeII emission, although its continuum variation is slight. ZTF18aajupnt/AT2018dyk was reported by Frederick et al. (2019) as a particular CL-NLS1 that transformed from a low-ionization nuclear emission-line region (LINER; Heckman 1980) in its “turn-off” state. Two other cases (SDSS J1236511+453904, SDSS 1406507-244250) were identified by Hon et al. (2020, 2022). In addition, large-amplitude variation has been reported in other two NLS1s — CSS 100217 (Drake et al. 2011) and PS16dtm (Blanchard et al. 2017).
Detailed studies, however, indicate that the significant variation is caused by either a Type IIn supernova or a tidal-disruption event (TDE; Drake et al. 2011; Saxton et al. 2018; Blanchard et al. 2017).

In addition to the CL phenomenon that occurred in the Balmer lines, SDSS J025951.22+003744.2 can be identified as an Mg II CL-AGN (see the insert panel in Figure 2 and the lower panel in Figure 5). Along with the two “turn-on” candidates, Guo et al. (2019) identified SDSS J152533.60+292012 as the first Mg II CL-AGN.

SDSS J025951.22+003744.2 is interesting in its repeat CL phenomenon. To date, there are only eight confirmed repeat CL-AGNs: Mrk 590, Mrk 1018, NGC 1566, NGC 4151, NGC 7603, Fairall 9, 3C 390.3, and UGC 3223 (Marin et al. 2019; Parker et al. 2019; Wang et al. 2020; Mathur et al. 2018).

6.3.2 Narrow-Line Region

The “turn-off” (or dim) state of the object provides us an opportunity to study the narrow-line region (NLR) of NLS1s. Compared to the “turn-on” state in 2004, the measured total [O III] λ5007 line flux decreases by a factor of $\sim 4.5$ in the “turn-off” state. We argue that this decrease could be well understood in the context of the intermediate-width emission-line regions (IELRs) located between the classical BLRs and NLRs (e.g., Brotherton 1996; Mason et al. 1996; Hu et al. 2008; Zhu et al. 2009), in which the observed dramatic [O III] λ5007 variation resulted from a blueshifted and broad component. Initially, the measured [O III] λ5007 line width is $270 \pm 10$ km s$^{-1}$ in the “turn-off” state. However, in addition to a narrow component with a width of $300 \pm 10$ km s$^{-1}$, a blueshifted and broad component (FWHM = $810 \pm 20$ km s$^{-1}$) is required to model the [O III] λ5007 profile observed in the 2022 “turn-on” state. Our line-profile modeling suggests that in the “turn-on” state, roughly half of the [O III] λ5007 emission comes from the “blue wing,” which results in a narrow-line ratio $[\text{O III}]/H\beta \approx 4.9$. This ratio is highly consistent with the value of $\sim 4.6$ determined from the “turn-off” state. There is also observational evidence in other objects supporting a rapid variation of the [O III] λ5007 blue wing within a timescale of one year (e.g., Wang et al. 2005).

The coincidence of the “turn-off” state and disappearance of the [O III] λ5007 blue wing implies a common physical driver between CL phenomenon and AGN feedback. The [O III] λ5007 blue wing is widely used as a good tracer of AGN-driven outflow and feedback of the central SMBH (e.g., Veilleux et al. 2005; Komossa et al. 2015, 2018; Woo et al. 2016; Luo et al. 2021; Wang et al. 2011, 2018), although the underlying physical process is still much debated. Possible drivers of AGN outflow include radiation pressure acting on dust (e.g., Thompson et al. 2015), accretion disk winds proceed into the inner NLR (e.g., Proga et al. 2008; Komossa et al. 2008; Wagner et al. 2013), and jet–cloud interactions in radio objects (e.g., Saxton et al. 2005; Wagner et al. 2012; Mullaney et al. 2013).

Based on the “turn-off” spectrum with better measurements of narrow emission lines, the two empirical Baldwin–Phillips–Terlevich (BPT) diagrams are shown in Figure 10 for the 14 newly identified CL-AGNs. The diagrams, which were originally proposed by Baldwin et al. (1981) and then refined by Veilleux & Osterbrock (1987), are traditionally used as a powerful tool to determine the dominant energy source in emission-line galaxies according to their emission-line intensity ratios. One can see from the figure that, except for two objects (SDSS J120255.34+574411.7 and SDSS J161003.12+543627.8) associated with relatively young circumnuclear stellar populations assessed by their small $D_n(4000)$ values, all the CL-AGNs, including the CL-NLS1 SDSS J025951.22+003744.2, occupy the typical AGN region (see also Figure 13 of Jin et al. 2022). This supports the above proposed scenario that CL-AGNs are probably at an evolutionary transition stage owing to their ceased star-formation activity. For SDSS J025951.22+003744.2, in addition to Figure 10, its [O III] λ5007/[O II] λ3727 narrow-line ratio is measured to be $\log([\text{O III}]/[\text{O II}]) = 0.33$ which is also typical of Seyfert 2 galaxies (e.g., Kewley et al. 2006). These measurements motivate us to believe that the narrow-line emission of some NLS1s is free of contamination caused by possible circumnuclear star formation.

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6 In deriving this line ratio, extinction corrections are applied to both [O III] λ5007 and [O II] λ3727; the extinction is estimated from the Hα/Hβ narrow-line ratio in standard Case B recombination.
Finally, a revised estimate of $L/L_{\text{Edd}}$ in the “turn-off” state is 0.20, after scaling the spectral flux by only the narrow component of [O III] $\lambda$5007.

### 6.3.3 Rapid “Turn-on” Process

SDSS J025951.22+003744.2 is also interesting in its rapid “turn-on” process. Compared to the SDSS-V spectrum taken in 2021, our follow-up spectroscopy taken with the Keck I telescope reveals a rapid “turn-on” process with a timescale of $\sim 1$ yr. With $M_{\text{BH}} = 4.7 \times 10^7 M_\odot$, the timescale of a typical TDE is predicted to be $\Delta t = 0.35(M_{\text{BH}}/10^7 M_\odot)^{1/2}(M_*/M_\odot)^{-1}(R_*/R_\odot)^{3/2} \approx 1$ yr (e.g., Rees 1988; Lodato & Rossi 2011, and references therein), where $M_*$ and $R_*$ are respectively the mass and radius of the disrupted star. Although this prediction is comparable to the observed CL timescale, it is difficult for the TDE scenario to explain the repeat CL phenomenon identified in the object, because the TDE rate is expected to be as low as one event every $10^4$–$10^5$ yr per galaxy (e.g., Gezari et al. 2008; Donley et al. 2002; van Velzen et al. 2014).

Based on the short timescale of $\sim 1$ yr, variation of the obscuration is unlikely to explain the CL phenomenon observed in this object. With obscuration material orbiting outside the BLR in a circular Keplerian orbit, the crossing time can be estimated from Eq. (4) of LaMassa et al. (2015):

$$t_{\text{cross}} = 0.07 \left( \frac{r_{\text{orb}}}{1 \text{ ld}} \right)^{3/2} \sin^{-1} \left( \frac{r_{\text{arc}}}{r_{\text{orb}}} \right) \left( \frac{M_{\text{BH}}}{10^8 M_\odot} \right)^{-1/2},$$

where $r_{\text{orb}}$ and $r_{\text{arc}}$ are the orbital radius of the obscuring material and the true size of the BLR, respectively. Combining Eq. (3) and the radius-luminosity relationship $\log(R_{\text{BLR}}/1 \text{ ld}) = 1.559 + 0.549 \log(\lambda L_\lambda(5100 \AA)/10^{44})$ erg s$^{-1}$ given by Benz et al. (2013) yields a BLR radius of $R_{\text{BLR}} \approx 80$ light days, resulting in $t_{\text{cross}} > 70$ yr when $M_{\text{BH}} = 4.7 \times 10^7 M_\odot$ and $r_{\text{orb}} \approx r_{\text{arc}} = R_{\text{BLR}}$ are used.

We argue that viscous radial inflow is not a plausible scenario for the observed rapid CL phenomenon, either. The viscous timescale of a viscous radial inflow can be estimated as (e.g., Shakura & Sunyaev 1973; Krolik 1999; LaMassa et al. 2015; Gezari et al. 2017)

$$t_{\text{infl}} = 6.5 \left( \frac{\alpha}{0.1} \right)^{-1} \left( \frac{L/L_{\text{Edd}}}{0.1} \right)^{-2} \left( \frac{\eta}{0.1} \right)^2 \left( \frac{r}{r_g} \right)^{7/2} \left( \frac{M_{\text{BH}}}{10^8 M_\odot} \right) \text{ yr},$$

where $\alpha$ is the “viscosity parameter,” $\eta$ the efficiency of converting potential energy to radiation, and $r_g$ the gravitational radius in units of $GM/c^2$. Taking the fiducial values of $\alpha = \eta = 0.1$, the measured $M_{\text{BH}} = 4.7 \times 10^7 M_\odot$, and $L/L_{\text{Edd}} = 0.6$ yields $t_{\text{infl}} \approx 20–200$ yr, when $r \approx (50–100)r_g$ is adopted to account for the outer disk producing optical emission.

We argue that the local disk thermal instability is a plausible scenario to account for the short timescale, which predicts a thermal timescale of $t_{\text{th}} \approx 5$ yr according to the evolutionary $\alpha$-disk model developed by Siemiginowska et al. (1996):

$$t_{\text{th}} \approx \frac{1}{\alpha \Omega_K} = 2.7 \left( \frac{\alpha}{0.1} \right)^{-1} \left( \frac{r}{10^{16} \text{ cm}} \right)^{3/2} \left( \frac{M_{\text{BH}}}{10^8 M_\odot} \right)^{-1/2}.$$

Additionally, in order to match the theoretical predictions to the observed CL timescales, a shorter variability timescale can be obtained either by introducing a narrow unstable zone (Sniegowska et al. 2020), or by involving an accretion disk elevated by a magnetic field (e.g., Ross et al. 2018; Stern et al. 2018; Dexter & Begelman 2019), which is supported by recent numerical simulations carried out by Pan et al. (2021).

### 7 CONCLUSIONS

We identify 14 new CL-AGNs at $z < 0.5$ by comparing the SDSS-V/BHM dataset, the SDSS DR16 spectroscopic dataset, and our follow-up spectra taken with both the Lick Shane 3 m and Keck 10 m telescopes. With detailed analysis of these spectra, the following conclusions were found:
1. Based on a sample of 65 CL-AGNs compiled from this and previous studies, we reinforce the conclusion that CL-AGNs tend to be biased against a high Eddington ratio, implying that the disk-wind BLR model is a plausible explanation of the CL phenomenon.

2. The host galaxies of 12 out of the 14 new CL-AGNs tend to be dominated by intermediate-age stellar populations, consistent with the results recently reported by Liu et al. (2021) and Jin et al. (2022). The intermediate-age stellar population motivates us to propose that CL-AGNs are probably AGNs at a special evolution stage, going from a plentiful supply of cold gas to fueling by the slow stellar winds of evolved stars — that is, at a transition stage from “feast” to “famine” SMBH fueling.

3. Thanks to our spectroscopic follow-up observations \( \sim 1 \text{yr} \) after SDSS-V, we identify SDSS J025951.22+003744.2 as a new repeat CL-NLS1 with a rapid “turn-on” timescale of \( \sim 1 \text{yr} \). This rapid “turn-on” process implies that the CL phenomenon in the object could have resulted from a local disk thermal instability.

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Fig. 6 Illustration of analysis for the multi-epoch spectra of SDSS J025951.22+003744.2. *Left column:* modeling and removal of the continuum by a linear combination of a set of components, except the SDSS-V spectrum observed in 2020 (see main text for details). In each panel, the top-blue curve shows the continuum-removed emission-line spectrum. The heavy black curve underneath shows the observed rest-frame spectrum, overplotted by the best-fit continuum indicated by the red curve. The light-black curves under the observed spectrum present the individual components used in the modeling. The spectra are shifted vertically for clarity. *Middle column:* an illustration of the line-profile modeling with a linear combination of a set of Gaussian functions for the H\textbeta\ region. In each panel, the modeled continuum has already been removed from the originally observed spectrum. The observed and modeled line profiles are plotted with black and red solid lines, respectively. Each used Gaussian function is shown by a dashed line. The subpanel underneath the line spectrum presents the residuals between the observed and modeled profiles. *Right column:* Same as the middle column, but for the H\textalpha\ region.
This study compiled sample

Fig. 7 Distributions of the CL-AGNs on the $L_{\text{bol}} - M_{\text{BH}}$ (left column) and $L_{\text{bol}} - L_{\text{bol}}/L_{\text{Edd}}$ (right column) diagrams, after combining the 14 new CL-AGNs (denoted by circles) identified in this study and the 26 previously identified CL-AGNs (denoted by squares) complied by Wang et al. (2019). The “turn-on” and “turn-off” states are displayed in the upper and lower rows by the solid and open symbols, respectively. The underlying comparison samples are described as follows. Red crosses, quasars with $z < 0.5$ taken from the value-added SDSS DR7 quasar catalog (Shen et al. 2011); green crosses, the SDSS DR3 NLS1 catalog established by Zhou et al. (2006); and magenta crosses, the SDSS DR7 intermediate-type AGNs studied by Wang (2015). The Swift/BAT AGN sample of Winter et al. (2012) is shown by the blue, yellow, and cyan crosses for Seyfert 1, 1.2, and 1.5 galaxies, respectively.
Fig. 8 MIR light curves of the 14 new CL-AGNs detected by WISE. Each light curve is binned by averaging the measurements within one day. In each panel, the vertical dashed lines mark the epochs of optical spectra, where the blue line corresponds to a “turn-on” state and the red one to a “turn-off” state.
Fig. 9 $L_{bol}/L_{Edd}$ plotted as a function of stellar population age index $D_n(4000)$. The 12 newly identified CL-AGNs having available $D_n(4000)$ are shown with black solid and open circles for their “turn-on” and “turn-off” states, respectively. The black open triangles denote the values of $L_{bol}/L_{Edd}$ averaged between the “turn-on” and “turn-off” states. The red-solid and blue-open squares are the local partially obscured Seyfert galaxies and composite galaxies studied by Wang (2015), respectively. The dashed line is the best-fit nonlinear relationship to these partially obscured AGNs.
Fig. 10 Two BPT diagnostic diagrams for the 14 newly identified CL-AGNs indicated by the red solid circles. The location of CL-NLS1 SDSS J025951.22+003744.2 is marked by the blue open circle in each panel. The density contours are shown for a typical distribution of the narrow-line galaxies described by Heckman et al. (2004) and Kauffmann et al. (2003). Only the galaxies with SNR > 20 and the emission lines detected with at least 3σ significance are plotted. The solid lines in both panels mark the theoretical demarcations separating AGNs from star-forming galaxies (“starburst galaxies,” marked “SB”) proposed by Kewley et al. (2001). The long-dashed line in the left panel shows the empirical demarcation proposed by Kauffmann et al. (2003), which is used to separate “pure” star-forming galaxies. The objects between the empirical and theoretical demarcations are the so-called “transition objects” (or “composite galaxies”), marked “TO.” The dot-dashed line in the right panel is the demarcation separating Seyfert galaxies and LINERs reported by Kewley et al. (2006).