Literature Review on Changing-Looking Quasars(CLQs)

Jiarong Zhu

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Abstract

Changing-look quasars are recently discovered to be quasars that show large variability in their luminosity, accompanied by emergence or disappearance of broad emission components. By searching through archival spectra/photometric data and performing follow-up spectroscopic observation on selected CLQ candidates, more sample of CLQs were revealed and brought more challenges to this field. The physical origin of CLQ variability is under debates, intrinsic changes in the quasar's accretion process appears to be more likely than extrinsic origins such as variable dust obscuration. In general it is hard to answer many of the questions about CLQs unless more CLQs are identified and more data sets of repeat spectroscopy are available.

1 Introduction

Quasars are thought to be Active Galactic Nucleus(AGNs) at a stage where rapid accretion is on and the luminosity is extremely high. The quasar phases are relatively short in the life of AGNs, generally lasting 10^{7-8}years[11].

Our current understanding of AGN is referred as AGN's unification model, with a sketch in Figure 1. The accretion disk surrounding the black hole emits the bulk part of the optical and UV continuum; the central region of the accretion disk emits most of the X-ray radiation; the optically thick dust torus obscures the center if viewing from a direction near the plane of the disk; the gas cloud close to the center is where broad emission lines are emitted; the gas cloud much further away is responsible for narrow emission lines. Broad/narrow emission lines are produced because broad/narrow line region are ionized by the AGN continuum.

AGN are known to be variable, but it is only relatively recently that multi epoch spectra of the same AGN become available. In previous studies, dramatic changes in spectral state have been observed in X-ray binaries. As a different phenomenon, optical changing-looking AGNs are also observed. Characteristic large changes in Balmer broad line emissions(BLEs)shows the AGNs have transitioned from Type 1 to Type 1.8-2.0, or vice versa(e.g.,[12]). By scaling the timescale of X-ray binaries transition to $\sim 10^8 M_\odot$ super massive black holes, transition timescale in quasars is estimated to be $\sim 10^{4-5}$years[13]. Indirect evidence from fading AGNs' extended emission-line regions has indicated a transition timescale of $\sim 10^4$years.[7] Due to the long timescale, the probability of observing such transition is thought to be small.

With the first discovery of Changing-looking quasar(CLQ) by LaMassa et al.[1] from the SDSS Stripe 82X survey, this kind of AGN transition is extended to high luminosity and redshift regime. Repeated spectroscopy of this quasar(SDSS J015957.64+003310.5) showed that the rest-frame timescale of the observed transition is $\sim$ 7 years, much shorter than the expected timescale $\sim 10^4$years. Since the first CLQ, many efforts have been made on identifying more CLQs and revealing more of their properties.

2 Techniques

The most frequently used techniques in searching for changing-look quasars are photometric, spectroscopic and time-domain sky surveys. In [1] the CLQ was a X-ray selected AGN from SDSS Stripe 82X and analyzed with optical, X-ray spectra and optical photometry. In [3] the author applied archival search in the SDSS Data Release 12. In [9]the author performed systematic search based on repeat photometry from SDSS and Pan-STARRS1, along with repeat spectra from SDSS and SDSS-III BOSS. In [2] the authors did follow-up spectroscopy using spectroscopically confirmed quasars from SDSS DR7 catalog, they used photometry from the Catalina Sky Survey to verify variability behavior of CLQ candidates, then confirmed CLQs with optical spectroscopy from the William Herschel, MMT, Magellan and Palomar telescopes.

In the data analysis procedures, spectral decomposition is commonly used to analyze the spectra.

3 Observations

In recent studies, CLQs are identified as Active Galactic Nuclei (AGN) with high luminosity $L_{bol} > 10^{44} erg\ s^{-1}$ that show strong variability in their optical/UV continuum and Broad Emission Line(BEL) flux, over rest-frame timescale $\sim$ 10 years. There is no standard algorithm of searching for CLQs, so far CLQs are mostly selected by searching in quasars with specific conditions, for example $\Delta g > 1$, then selected by visual inspection. Systematic search for CLQs in archival repeat spectra of quasars(Ruan et al.[3]) as well as follow-up spectroscopic search (Macleod et al.[2]) have revealed ~20 CLQs and $\sim$ 200 CLQ candidates.

Macleod et al. in[2] presented till now the largest sample of identified CLQs. Overall the CLQs have undergone a dramatic brightening or dimming in the light curve between the spectral epochs, accompanied by emerging or disappearing Balmer BELs, but in most cases the timescale for the change can not be resolved. It is also observed that when dimming, if the Balmer BELs dim but still appear, their widths are broadened. A few CLQ examples are shown in Figure 2. We see an overall dimming in the continuum, as well as strong dimming in broad emission lines.

In most cases observed by [2], CLQs dim rather than flare. The dimming type is also called "turn-off" type while the contrast is "turn-on" type. As an example, Wang et al. in [14] presented a turn-on CLQ transition, with non-detectable Hβ broad lines at early epoch but strong Balmer emission lines at later epoch.

In [2], the author studied whether the continuum change and BEL change are correlated. With limited sample sizes, it looks like the luminosity and flux change of the continuum at 3240A is proportional to those of Hβ, stronger Balmer line variability happens with stronger variation in continuum. Whether this trend holds for larger sample is to be studied. If that is confirmed, it would mean the spectral energy distribution keeps constant during the transition.

There are CLQ samples that show other behavior, such as strong variability in other elements' broad emission lines like He II, Fe II; flickering in the light curves; asymmetric broad Balmer lines, etc. These behavior may reveal interesting physical condition of the sources that are worth studying.

4 Physical Origin

The physical origin of the CLQ variability is uncertain. Many efforts have been put on determining whether the CLQ variability is due to intrinsic or extrinsic origin, intrinsic origin meaning origin related to the accretion process that emits the AGN continuum and extrinsic origin meaning origins like variable absorption blocking the line-of-sight. The intrinsic arguments, especially changes in accretion rate or accretion disk structure appear to be more likely than extrinsic arguments related to obscuration.

4.1 Intrinsic? Dependence upon luminosity, black hole mass and the Eddington ratio

Wilhite et al. [5] and LaMassa et al.[1] both pointed out that their CL quasars, when dimming in broad line luminosity, the broad line widths are broadening such that the derived black hole masses are preserved. This phenomenon is consistent with the change in the Eddington ratio.

The Eddington ratio is defined as L_{bol}/L_{Edd}, where L_{bol} is bolometric luminosity and L_{Edd} is Eddington luminosity, meaning the maximum luminosity a body can have, at which luminosity the force of radiation reaches balance with the force of gravity. For variable quasars, it is well known that the amplitude of variability is anti-correlated to luminosity. An example is given in [4] Figure 11. I put it here as Figure 4.

In [5] Wilhite et al. studied repeat spectra of $\sim$ 8000 quasars from SDSS and derived their black hole masses, then they studied the correlation between luminosity, variability and black hole mass. They reproduced the anti-correlation between luminosity and variability and found the anti-correlation was independent of the black hole mass. They also probed the relation between variability and central black hole mass. Combining both, they point out that independent of the black hole mass, the Eddington ration is anti-correlated to the amplitude of optical variability further meaning the the Eddington ratio could be driving the quasar variability.

Although the physical process causing the variability is unknown, there is a damped random walk model that can explain the observed light curves of quasars pretty well, thus this model can be a nice tool. In [10] Macleod et al. applied this model on $\sim$9000 confirmed quasars in SDSS Stripe 82 and found correlations between some variability parameters and physical parameters. Their modelling once again confirmed the anti-correlation between variability and the Eddington ratio, once again supported the scenario that quasar optical variability is tied to accretion process.

Macleod et al. in [2] have confirmed the trend also in their CLQs that CLQs in general are at lower Eddington ratios than the control sample. This trend is consistent with the anti-correlation between Eddington ration and variability, favoring an intrinsic origin related to dramatic change in the accretion flow of the AGN.

In a word, many evidences have shown that quasar variability might be driven by the Eddington ratio change, which in fact represents changes either in the accretion rate or in the accretion disk structure.

4.2 Extrinsic?

4.2.1 Dust extinction

LaMassa et al.[1] argue that obscuration by a dust cloud outside the Broad Line Region is unlikely, because the timescale for light to across the BLR is would be much longer than the observed transition timescale.

Apart from the timescale argument, LaMassa et al.[1] and Ruan et al.[3] have both analyzed whether the extinction model could explain the variability. They dereddenned the decomposed quasar spectrum and fitted E(B-V) such that the dimming of the continuum could match the early epoch. They found that although the change by extinction could reasonable explain the dimming of the continuum, it could not reproduce observed spectrum in the Hα emission(see Figure 3). Ruan et al.[3] also argued that the broadening of Hα component could not be explained by dust extinction, because that implied less emission from the outer part of BLR than from the inner part, which could not be due to dust.

4.2.2 TDEs

Tidal Disruption Event(TDE) was suggested to be an explanation. Ruan et al.[3] ruled out this possibility for their CLQ samples by analyzing narrow emission lines. The observed narrow lines, if produced by TDE, it would take 10^{3-4} years for light to travel through the narrow line region, order of magnitude longer than the timescale of CLQ dimming or flaring. Also, the BPT diagram of the three CLQs in their paper shows they are AGN-like ionizing continuum. The BPT diagram is shown in Figure 5. Besides, their CLQs have shown strong [OIII]λ5007 narrow emission line, their flux ranged from $(1.2-1.7)*10^{-15} ergs^{-1}cm^{-2}$, while UV/optical TDEs should have no or much fainter [OIII]λ5007 emission(e.g.[6]). For those faint [OIII]λ5007 lines detected in TDEs, they have ratios relative to other lines that are consistent with star formation rather than AGN photoionization. All these arguments suggested the three CLQs in [3] are linked to quasar activity rather than TDEs.

4.2.3 Other

Rumbaugh et al.[4] pointed out that the effect of orientation should not be the reason. They argued that although with the system viewed more pole-on the continuum flux from the disk would be larger and thus broad line Equivalent Width(EW) would be reduced, this interpretation could not explain the observed correlation between EWs and extremely variable quasars. Macleod et al.[2] pointed out their samples lacked foreground spectral features, their variability were unlikely to be due to lensing by foreground galaxies or microlensing by foreground stars.

5 Key questions

The changing-looking quasar phenomenon is quite a new area, awaiting more identified samples with more informative data as well as satisfying explanations for the nature of the variability. Here are some of the key issues to be solved.

1. Are CLQs merely tail of some continuous distribution of quasar properties? Or are they standing out as a distinct population?

2. Satisfying explanations for the physical origin of CLQ transition.

3. No good theoretical timescale can be applied to explain the observed CLQ transition timescale. The viscous timescale in the optical-emitting region of the disk, which is the timescale of mass flow, is ~years, orders of magnitude longer than the observed CLQ transition timescale. The dynamical time(~hours to days), roughly is the shortest timescale on which we can see physical changes in a region, is usually too short compared to CLQ transition timescale, while the sound crossing time(~years), the timescale on which perturbations may transmit across a region, is too long. See Figure 6 for example (cited from [8]). Whether the calculation of viscous timescale is wrong or a better timescale should be proposed is to be studied.

4. Multi-wavelength observations are needed, more samples of CLQ are needed, larger data set of repeat quasar spectroscopy is needed.

5. More well-sampled light curves of quasars are need for determining the transition timescale and for selecting targets for follow-up observation.

6. So far most CLQs are "turn-off" CLQs, more "turn-on" CLQs are needed. This phenomenon probably results from the biased sample construction(e.g. in [2]the author search for CLQs based on DR7 quasar catalog, most of these quasars have broad BELs in the early state.) If in future work the suitable parent sample of quasars and proper method of searching for turn-on events are established, we would expect more "turn-on" events to appear.

7. Why the Mg II BEL is not showing as significant response to changes in continuum as the Balmer lines, as Mg II line is formed at a similar ionization energy as the Balmer lines?

6 Summary

In this review paper I tried to give an overview of the field, including observational phenomena, commonly used techniques, possible explanations and issues waiting to be solved in future work.

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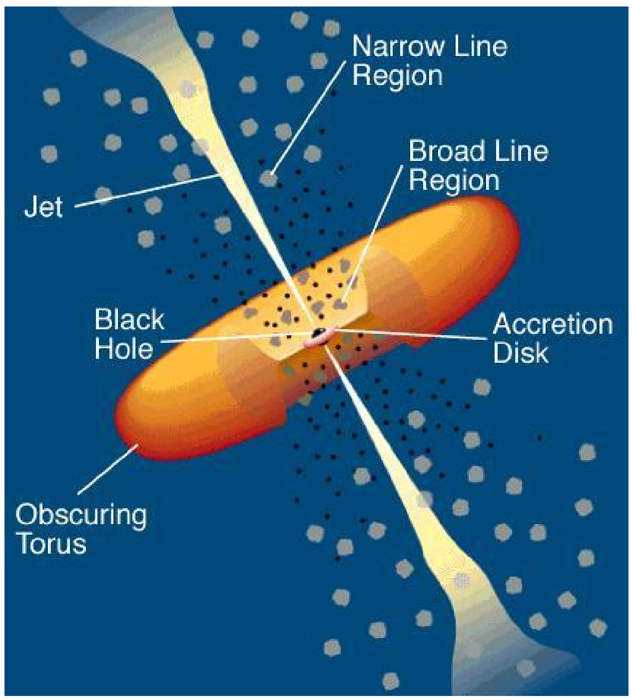

Figure 1: AGN's unification model, From Urry and Padovani (1995)

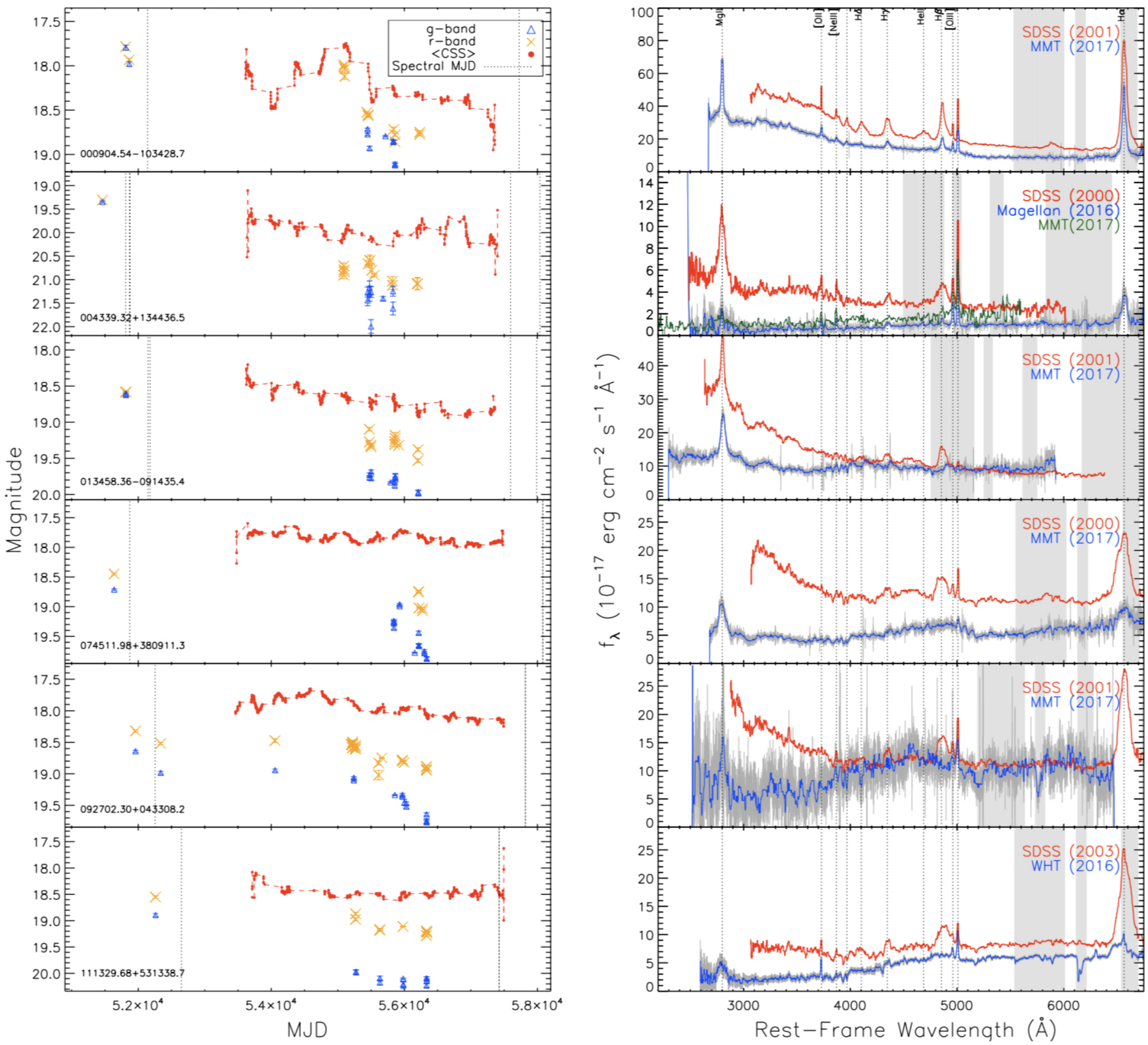

Fig. 2*a*

Figure 2: Left: variation of g-band magnitude with time. Right: Corresponding spectra at two epochs. The figure is from [2],Figure 2a.

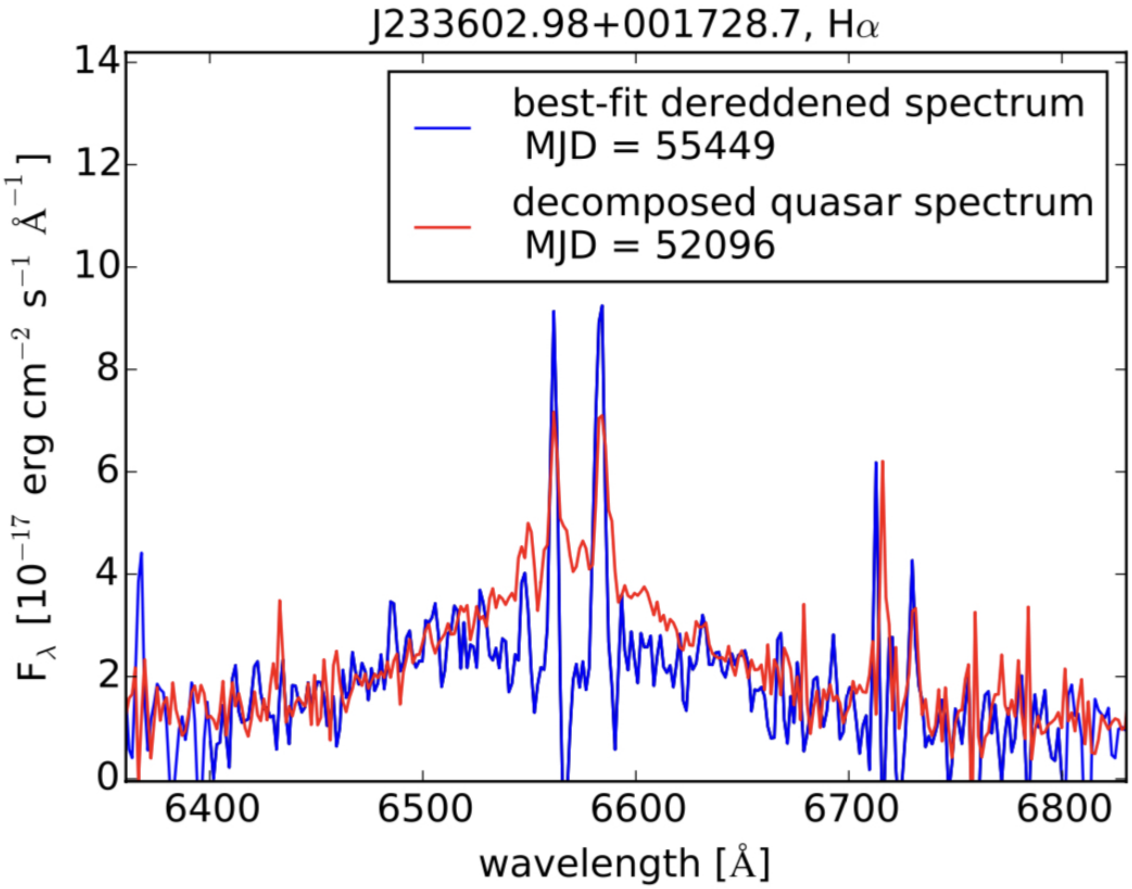

Figure 3: Figure 4 in [3], the best-fit dereddened spectrum could not reproduce H_α profile.

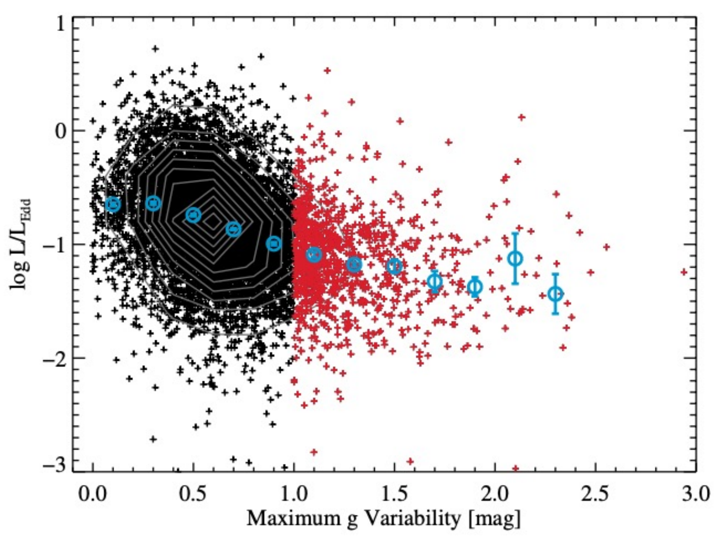

Figure 4: Anti-correlation between maximum g-band variability and the Eddington ratio estimated from SDSS spectrum. A decreasing trend is observed.

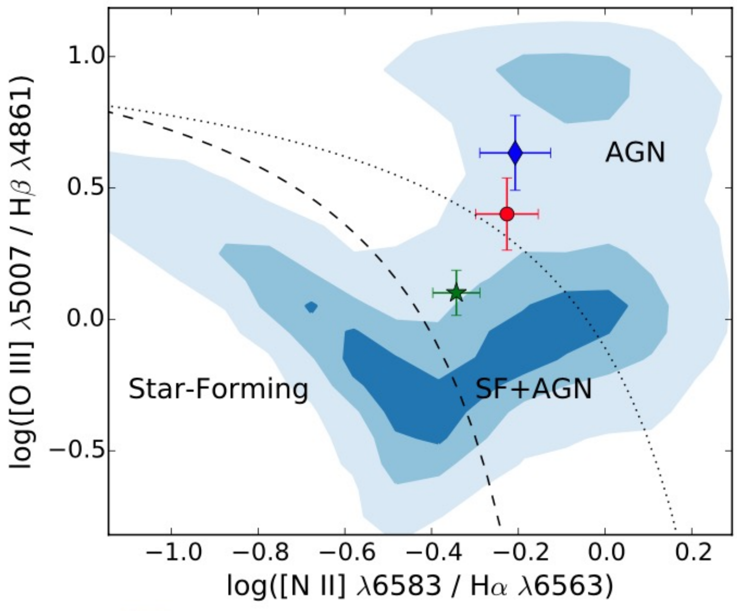

Figure 5: BTP diagram of the three CLQs in [3], showing the narrow emission lines of these CLQs are AGN-like, disfavoring TDE scenario

AGN Structure	physical size	angular size	t_{lt}	t_{dyn}	t_{snd}	t_{therm}
Inner disc	5 R_S	0.1μas	1.4hrs	4.3hrs	1.3 yrs	18.7days
Optical disc	50 R_S	1μas	14hrs	5.7days	23 yrs	1.6yrs
Broad Line Region	1000 R_S	20μas	11days	1.4yrs	800 yrs	–
Obscuring Region	$10^5 R_S$	2mas	3.1yrs	1.4kyrs	350 kyrs	–

Figure 6: Table of timescales from [8]. The timescales are light-crossing , dynamical, sound crossing and thermal timescale respectively.