A study of optical spectral of extreme variability quasars in their various states

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Abstract

Extremely variable quasars (EVQs) are a population of sources showing large optical photometric variability revealed by time-domain surveys. In this work, we present a comprehensive analysis of EVQs based on a large sample constructed from multi-year photometric data from SDSS and Pan-STARRS1. Our sample comprises 14,012 EVQs, the largest-ever constructed for this population. We investigate the spectral characteristics of EVQs by comparing the composed spectra with control samples and investigating the changes between different epochs. The composed spectra of EVQs have similar shape to control samples excepting clearly bluer (redder) continuum during bright (dim) states, which is consistent with the "bluer-when-brighter" trend widely seen in normal quasars. We find that the EVQs exhibit systematically larger equivalent widths and stronger broad wings in broad emission lines. These results indicate that the strong disc turbulence of EVQs would produce more BLR clouds and/or have harder ionizing spectra. We also observe the absence of long-term intrinsic Baldwin effect and line width breathing of $H\beta$. The lack of long-term correlation between the continuum and Hb broad line could be a key of changing-look phenomenon. Our findings provide insights into the nature of EVQs, the structures of the BLR, and highlight connections between EVQs and changing-look quasars.

Background

Changing-look quasars:
Quasars exhibit significant variations in spectra properties, transitioning between different AGN classification (Type 1 and Type 2) within a few years.

Extremely variable quasars:
A population of quasars that display substantial optical photometric variability over relatively short timescales, usually used as CLQ candidates.

Intrinsic Baldwin effect:
Equivalent width of certain emission lines, such as Hb, Mg II and C IV, tends to decrease as the continuum luminosity of the AGN increases.

Sample

Quasar catalog: SDSS DR14Q (526,356)
Light curve: SDSS + PanSTARRS
Selection criteria: $|\Delta g| > 1$ & $|\Delta r| > 0.8$
Subsample division: 5 from extremely bright state (EBS) to extremely dim state (EDS)
Control sample: Low variable quasar ($|\Delta g| < 0.4$) with matched z, L_{bol}, M_{BH}
Multi-spec sample: 1,259 sources. Half of them have a maximum spectral **gap > 3000 days**

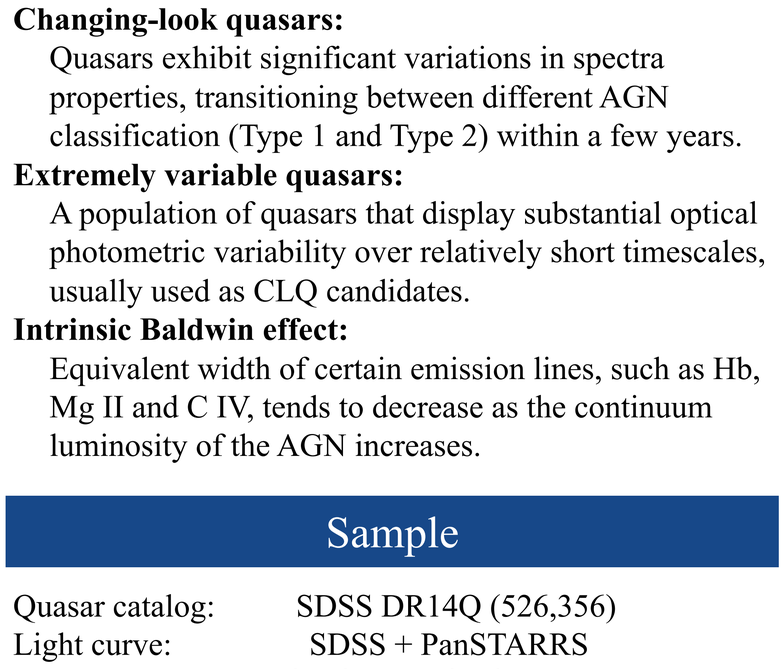

Figure 1. Criteria used to decide the spectral state of EVQs. $|\Delta g_{max}|$ is the largest change in g-band photometric magnitude for each source and the $g_{spec} - g_{mean}$ represents the deviation of the g-band synthetic spectral magnitude from the g-band mean photometric magnitude.

Results

Bluer-when-Brighter

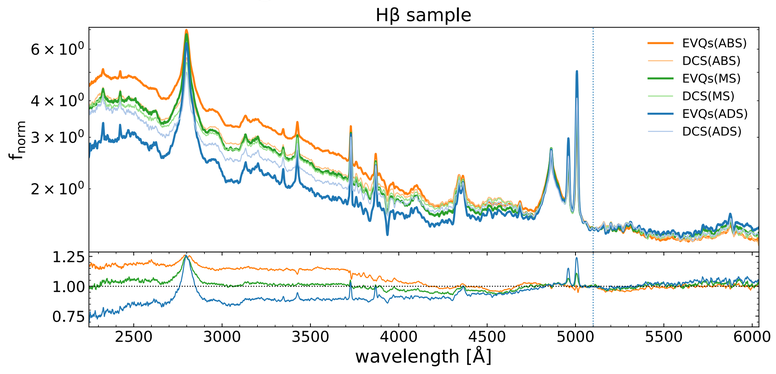

Figure 2. The stacked spectra and the spectral ratio of EVQs and their corresponding direct control samples (DCS). The ABS, including both EBS and BS, is clearly bluer than control samples. And the ADS, including both EDS and DS, is the opposite.

Systematically higher EW

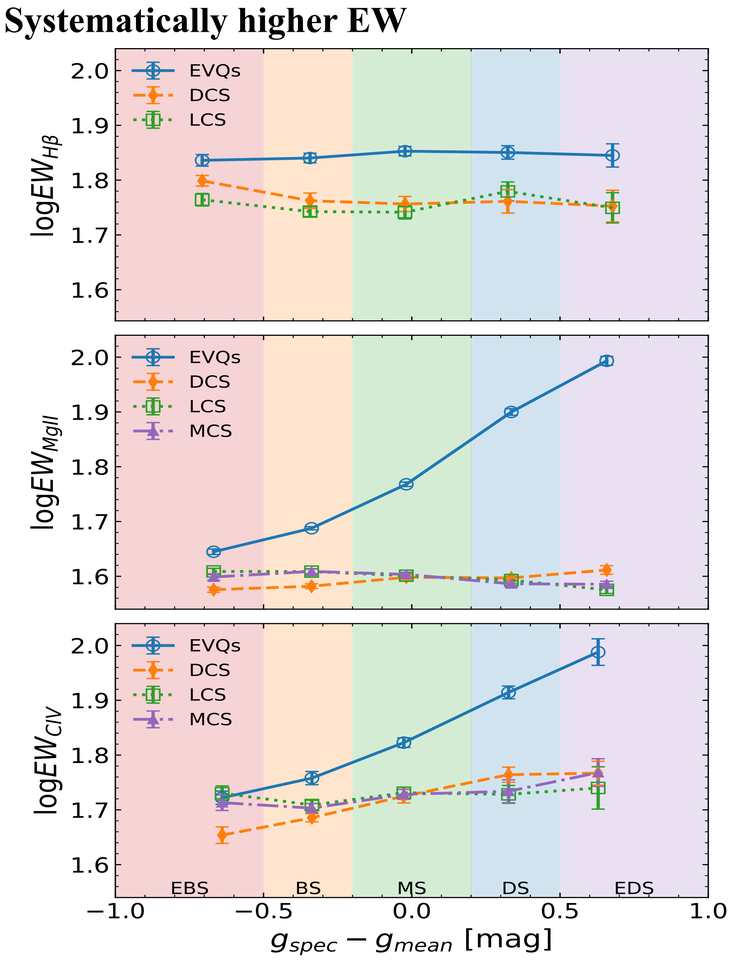

Figure 3. Emission line EWs measured from the stacked spectra of EVQs in different states, and of the corresponding control samples. The error bars are derived from bootstrapping the corresponding sample used to derive the stacked spectra. Three types of control sample are built. The DCS are the control sample with z, L_{bol}, and M_{BH} directly matched to EVQs. The L_{bol} of LCS is matched to the mean L_{bol} of EVQs. The M_{BH} of MCS is matched to the modified M_{BH} of EVQs considering the line width breathing effect.

EVQs line wing excess

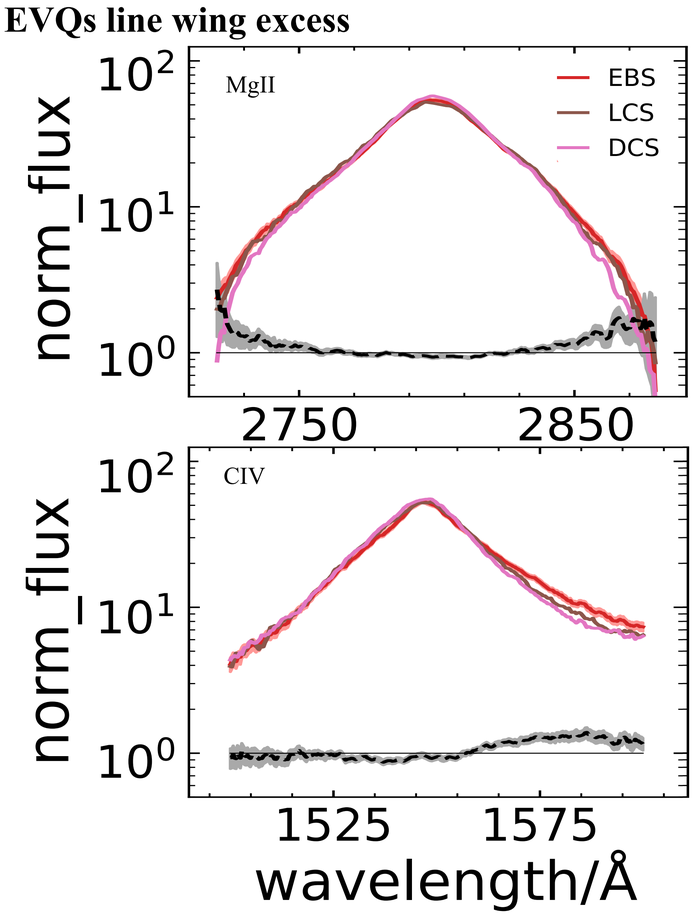

Figure 4. We use the stacked $Mg\ II$ and $C\ IV$ line spectra in extremely bright state (EBS) as examples of EVQs line wing excess. The spectra are normalized by the line fluxes. The black dashed lines are the difference spectra between EVQs and DCS with 1σ error dashed.

Line width breathing of $H\beta$

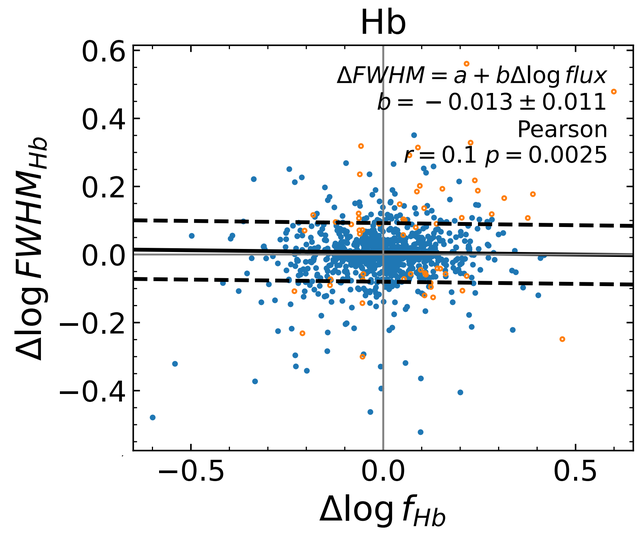

Figure 5. The EVQ correlation between FWHM variability and that of emission line flux. The variability of each single-epoch measurement is determined by subtracting the mean of all spectral measurements of the same EVQ. The black solid line and the dashed lines are the linear fit results and the standard deviation of data. The yellow dots are clipped by *ltsfit* according to data error. No breathing trend in our long gap sample.

Disappearance of $H\beta$ iBeff

We include archived 79 $H\beta$ CLQs and 61 $H\beta$ CLQ candidates from Green et al. (2022) in this section. The EVQs and CLQ candidates show no $H\beta$ iBeff while the CLQs have anti-iBeff. The $MgII$ of all three samples have strong iBeff.

Both CLQs and CLQs candidates have lower mean $EW_{H\beta}$ which is easily overwhelmed by spectral noise and identified as Type 2 by visual check when it is in dim state. The large flux change criteria in selecting CLQs prefer quasars with positive iBeff slope. Since the iBeff is scatter in $H\beta$ but consistent in $MgII$, our findings explain the scarcity of $MgII$ CLQs.

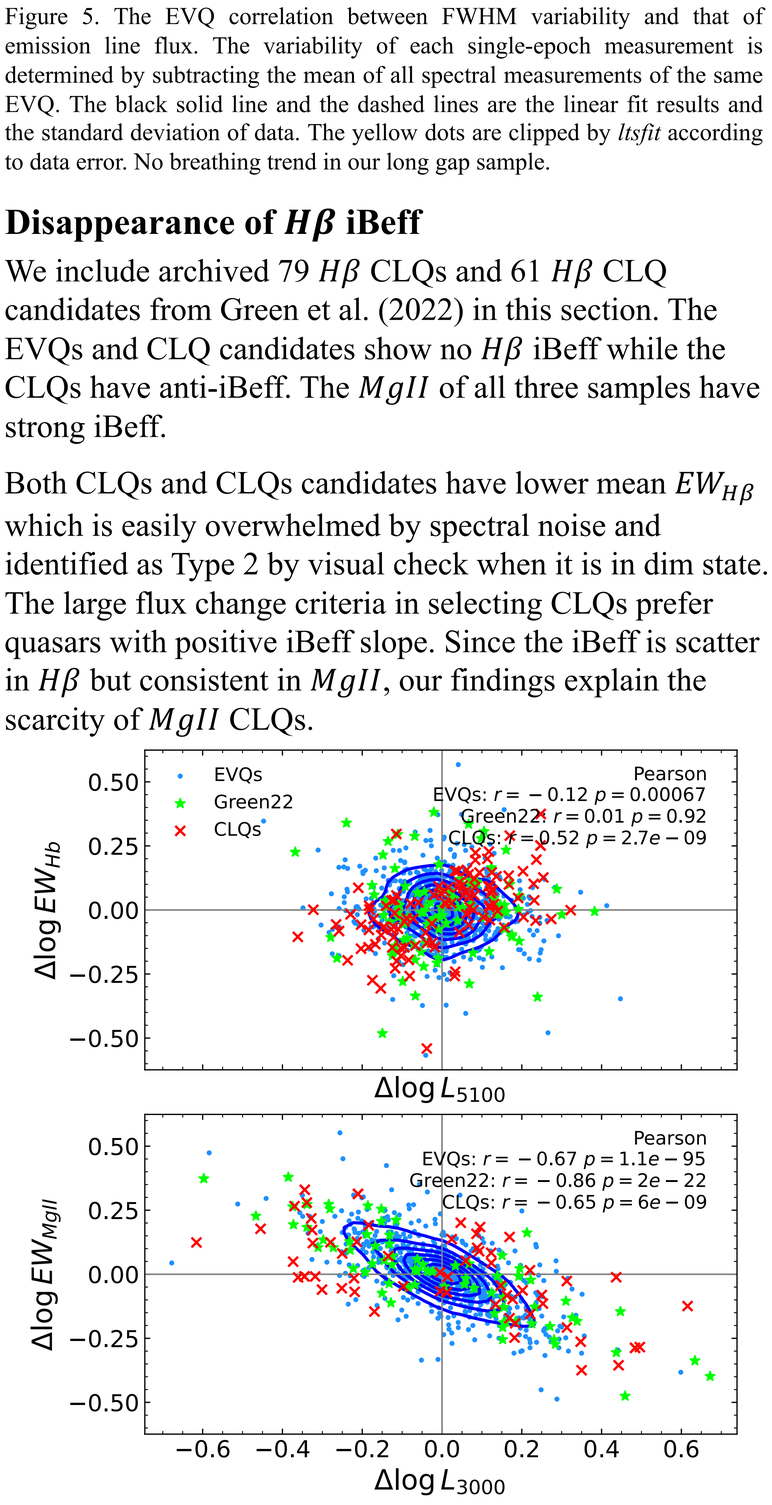

Figure 6. The correlation between the changes of line flux and the changes of line EW. The Pearson test results of each sample are listed.

Results

1. We composed a EVQs sample with 14,012 sources including 1259 targets with repeated observations
2. The BWB is clearly presented in EVQs, indicating that the EVQs have the same variable mechanism.
3. We do not observed a robust $H\beta$ iBeff, as seen in $MgII$, in EVQs. Thus, we propose that most of the present archived CLQs could be a selection bias instead of a distinct population according to its selection criteria.
4. We find no breathing in $H\beta$ and $MgII$ and anti-breathing in $C\ IV$. The disappearance of long-term $H\beta$ breathing could due to the structure change in $H\beta$ BLR.
5. The EW of broad lines of EVQs are systematically larger.
6. The EVQs line wings are stronger than control samples. And the excess of $C\ IV$ is red asymmetry.

References:
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