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Spectral Variability in Radio-Loud Quasars

Minfeng Gu
Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 Nandan Road, Shanghai 200030, China.
e-mail: gumf@shao.ac.cn

Abstract. The spectral variability of a sample of 44 Flat-Spectrum Radio Quasars (FSRQs) and 18 Steep-Spectrum Radio Quasars (SSRQs) in SDSS stripe 82 region is investigated. Twenty-five of 44 FSRQs show a bluer-when-brighter trend (BWB), while only one FSRQ shows a redder-when-brighter trend, which is in contrast to our previous results. Eight of 18 SSRQs display a BWB. We found an anticorrelation between the Eddington ratio and the variability amplitude in the *r* band for SSRQs, which is similar to that in radio-quiet AGNs. This implies that the thermal emission from the accretion disk may be responsible for the variability in SSRQs. The spectral variability from SDSS multi-epoch spectroscopy also shows BWB for several SSRQs, which is consistent with that from photometry.

Key words. Galaxies: active—quasars: general—galaxies: photometry—galaxies: spectroscopy.

1. Introduction

Active Galactic Nuclei (AGNs) exhibit variability at almost all wavelengths. The radio-loud quasars are divided into two populations, Flat-Spectrum Radio Quasars (FSRQs) and Steep-Spectrum Radio Quasars (SSRQs). In FSRQs, the non-thermal emission from a relativistic jet is usually dominant and Doppler-boosted, due to the small viewing angle. In contrast, SSRQs are usually lobe-dominated radio quasars, with a large viewing angle, and therefore, the beaming effect is not severe.

Although a bluer-when-brighter trend is commonly observed in blazars (e.g., Fan *et al.* 1998; Raiteri *et al.* 2001; Villata *et al.* 2002; Wu *et al.* 2007), the opposite trend of redder-when-brighter has also been found (e.g., Gu *et al.* 2006; Dai *et al.* 2009; Rani *et al.* 2010; Bian *et al.* 2012), especially in FSRQs (e.g., Gu *et al.* 2006). However, it is unclear whether a redder-when-brighter trend is generally present in FSRQs or not. Moreover, the optical and colour/spectral variations of SSRQs have been poorly studied, and the variability mechanism is largely unknown. For these reasons, we investigate the optical and spectral variabilities for a sample of radio-loud quasars (see details in Gu & Ai 2011a, b).

2. Sample

Our sample of 62 radio-loud quasars consists of 44 FSRQs and 18 SSRQs. The initial quasar sample was selected as those quasars found in both the SDSS DR7 quasar catalogue (Schneider *et al.* 2010) and Stripe-82 region. The Stripe-82 region, i.e. right ascension $\alpha = 20^{\mathrm{h}} - 4^{\mathrm{h}}$ and declination $\delta = -1^{\circ}.25 - +1^{\circ}.25$, was repeatedly scanned during the SDSS-I phase (2000–2005) and also during the course of a 3-month campaign in three successive years (2005–2007) known as the SDSS supernova survey. We cross-correlate the initial quasar sample with the Faint Images of the Radio Sky at Twenty cm (FIRST) 1.4-GHz radio catalogue (Becker *et al.* 1995), the green bank 6-cm (GB6) survey at 4.85 GHz radio catalogue (Gregory *et al.* 1996), and the Parkes–MIT–NRAO (PMN) radio continuum survey at 4.85 GHz (Griffith & Wright 1993). The radio spectral index α_ν was then calculated between the single or integrated FIRST and/or NRAO VLA Sky Survey (NVSS) 1.4 GHz and either/or both GB6 and PMN 4.85 GHz. We define a quasar to be a SSRQ according to its radio spectral index $\alpha_\nu > 0.5$ ($f_\nu \propto \nu^{-\alpha_\nu}$), and otherwise as FSRQs.

3. Results

3.1 *Spectra variability from photometry*

We directly used the point-spread-function magnitudes in the CAS Stripe-82 database from the photometric data obtained during SDSS-I phase from data release 7 and SN survey during 2005–2007. We found that all radio-loud quasars show more or less variations, ranging from 0.18 to 3.46 mag at the *r* band. FSRQs show more pronounced variations than SSRQs, with $\Delta r > 1.0$ mag in four FSRQs while none in SSRQs. By performing the correlation analysis between the spectral index and *r* band brightness, the redder-when-brighter trend is only found in one FSRQ SDSS J001130.400 + 005751.8 ($z = 1.4934$) (see Fig. 1), which could be explained by the thermal accretion disk emission as other FSRQs (Gu *et al.* 2006). In contrast, the

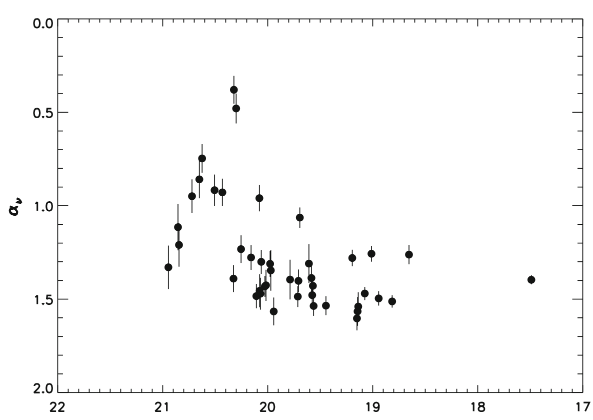

Figure 1. The relationship between the spectral index and PSF magnitude at the *r* band for SDSS J001130.40 + 005751.7 ($z = 1.4934$). A significant anticorrelation is present, which implies a redder-when-brighter trend.

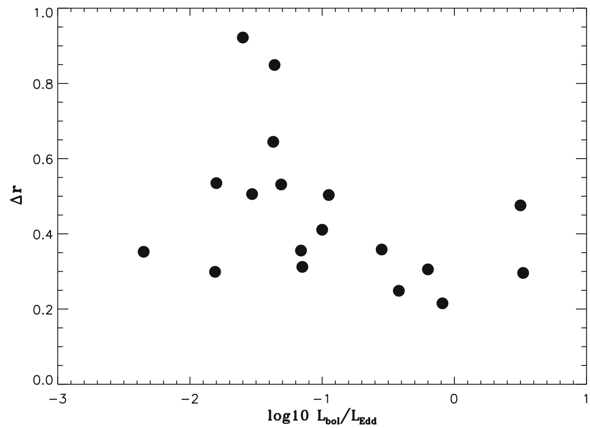

Figure 2. The Eddington ratio vs. the variability at the *r* band Δr for SSRQs.

bluer-when-brighter trend is more common in FSRQs (25 out of 44 sources), and in SSRQs (8 out of 18) as well. The results of FSRQs are in contrast to our previous results that FSRQs generally show the redder-when-brighter trend (Gu *et al.* 2006, see also Rani *et al.* 2010). For all SSRQs studied, we found an anticorrelation between the Eddington ratio and variability amplitude in the *r* band (Fig. 2), which is similar to that in radio-quiet AGNs. This implies that the thermal emission from the accretion disk may be responsible for the variability in SSRQs.

3.2 *Spectral variability from spectroscopy*

In 18 SSRQs, we have collected the multi-epoch spectroscopy for nine sources from SDSS. The significant variations were found in five sources. All these five sources

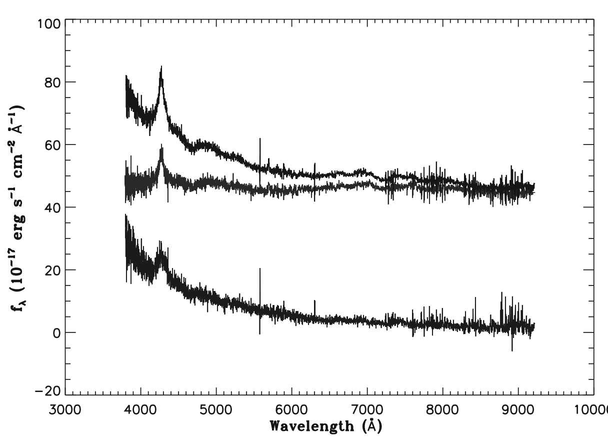

Figure 3. SDSS spectra of SDSS J022508.07 + 001707.2 ($z = 0.527$) in the observed frame. The top two lines show the spectra at two epochs shifted by a flux value of 40.0 to separate from the bottom one, which is the difference between the top two lines showing the variability between two epochs.

show BWB, which is consistent with the results from photometry (Gu & Ai 2011b). BWB has also been commonly found in a large sample of quasars selected from SDSS with multi-epoch spectroscopy (Guo & Gu 2014). However, RWB was found in a large fraction of FIRST bright quasars (Bian *et al.* 2012), even in radio-quiet quasars.

For our sample, an example is shown in Fig. 3 for SDSS J022508.07 + 001707.2 ($z = 0.527$). It can be directly seen from the spectra that the source becomes bluer when it gets brighter, which is also evident from the spectrum difference. Intriguingly, the residual of Mg-II line is apparent in the spectrum difference. As a matter of fact, the narrow lines are less variable, since the narrow line region locates typically at kpc scales, far from the nuclei. Therefore, the broad profile of the residual Mg-II line implies that the broad Mg-II line is also varying along with the variations in the continuum. This is in good agreement with the photoionization model and that the thermal emission is responsible for the continuum, although there might be a certain time delay between their variations.

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