Feeding Compact Objects: Accretion on All Scales
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The correlations between optical variability and physical parameters of quasars in SDSS Stripe 82

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Abstract. We investigate the optical variability of 7658 quasars from SDSS Stripe 82. Taking advantage of a larger sample and relatively more data points for each quasar, we estimate variability amplitudes and divide the sample into small bins of redshift, rest-frame wavelength, black hole mass, Eddington ratio, and bolometric luminosity, respectively, to investigate the relationships between variability and these parameters. An anti-correlation between variability and rest-frame wavelength is found. The variability amplitude of radio-quiet quasars shows almost no cosmological evolution, but that of radio-loud ones may weakly anti-correlate with redshift. In addition, variability increases as either luminosity or Eddington ratio decreases. However, the relationship between variability and black hole mass is uncertain; it is negative when the influence of Eddington ratio is excluded, but positive when the influence of luminosity is excluded. The intrinsic distribution of variability amplitudes for radio-loud and radio-quiet quasars are different. Both radio-loud and radio-quiet quasars exhibit a bluer-when-brighter chromatism. Assuming that quasar variability is caused by variations of accretion rate, the Shakura–Sunyaev disk model can reproduce the tendencies of observed correlations between variability and rest-frame wavelength, luminosity as well as Eddington ratio, supporting that changes of accretion rate play an important role in producing the observed optical variability. However, the predicted positive correlation between variability and black hole mass seems to be inconsistent with the observed negative correlation between them in small bins of Eddington ratio, which suggests that other physical mechanisms may still need to be considered in modifying the simple accretion disk model.

Keywords. Accretion, accretion disks — galaxies: active — galaxies: nuclei — quasars: general — techniques: photometric

1. Introduction

Although the study of variability plays an important role in investigating the nature of the compact central region in AGNs (Vanden Berk *et al.* 2004 Wilhite *et al.* 2008), the mechanism underlying quasar variability is still inconclusive. To clarify the nature of quasar variability, most previous studies focused on the dependencies of the variability indicator on redshift, time lag, rest-frame wavelength and luminosity (Vanden Berk *et al.* 2004, Wilhite *et al.* 2008, MacLeod *et al.* 2010). we revisit the correlations between the variability amplitude and physical parameters based on a sample of 7658 quasars in SDSS Stripe 82 (MacLeod *et al.* 2010, Sesar *et al.* 2007), with both the individual variability method and the detailed parameter binning techniques. Black hole masses, bolometric luminosities and Eddington ratios are obtained from the quasar catalog in Shen *et al.* (2011).

Table 1. Correlation between Variability and Each Parameter.

Radio loudness[1]	Parameter[2]	Restricted Params[3] $x1$, $x2$, $x3$	Spearman $r1$[4]	p[5]	Pearson $r2$[6]	Linear fit b[7]	a[8]
Radio-quiet	$\log z$	$R_{\rm EDD}$, $M_{\rm BH}$, $\lambda_{\rm rf}$	−0.081	0.189	−0.090	−0.049 ± 0.044	0.131 ± 0.009
Radio-quiet	$\log L_{\rm bol}$	z, $R_{\rm EDD}$, $\lambda_{\rm rf}$	−0.269	0.015	−0.260	−0.044 ± 0.020	2.128 ± 0.913
Radio-quiet	$\log L_{\rm bol}$	z, $M_{\rm BH}$, $\lambda_{\rm rf}$	−0.343	0.003	−0.335	−0.063 ± 0.020	3.032 ± 0.926
Radio-quiet	$\log R_{\rm EDD}$	z, $L_{\rm bol}$, $\lambda_{\rm rf}$	−0.167	0.137	−0.147	−0.020 ± 0.014	0.091 ± 0.011
Radio-quiet	$\log R_{\rm EDD}$	z, $M_{\rm BH}$, $\lambda_{\rm rf}$	−0.303	0.013	−0.299	−0.052 ± 0.019	0.075 ± 0.013
Radio-quiet	$\log M_{\rm BH}$	z, $L_{\rm bol}$, $\lambda_{\rm rf}$	0.113	0.235	0.104	0.013 ± 0.014	−0.002 ± 0.119
Radio-quiet	$\log M_{\rm BH}$	z, $R_{\rm EDD}$, $\lambda_{\rm rf}$	−0.203	0.057	−0.201	−0.033 ± 0.019	0.394 ± 0.168
Radio-loud	$\log \lambda_{\rm rf}$	$R_{\rm EDD}$, z, $M_{\rm BH}$	−0.187	0.218	−0.224	−0.225 ± 0.143	0.950 ± 0.494
Radio-loud	$\log z$	$R_{\rm EDD}$, $M_{\rm BH}$, $\lambda_{\rm rf}$	−0.153	0.306	−0.062	−0.034 ± 0.116	0.148 ± 0.028
Radio-loud	$\log L_{\rm bol}$	z, $R_{\rm EDD}$, $\lambda_{\rm rf}$	−0.266	0.297	−0.269	−0.058 ± 0.054	2.794 ± 2.456
Radio-loud	$\log L_{\rm bol}$	z, $M_{\rm BH}$, $\lambda_{\rm rf}$	−0.384	0.164	−0.321	−0.071 ± 0.055	3.373 ± 2.536
Radio-loud	$\log R_{\rm EDD}$	z, $L_{\rm bol}$, $\lambda_{\rm rf}$	−0.304	0.300	−0.274	−0.045 ± 0.032	0.079 ± 0.035
Radio-loud	$\log R_{\rm EDD}$	z, $M_{\rm BH}$, $\lambda_{\rm rf}$	−0.369	0.188	−0.291	−0.069 ± 0.047	0.056 ± 0.055
Radio-loud	$\log M_{\rm BH}$	z, $L_{\rm bol}$, $\lambda_{\rm rf}$	0.246	0.386	0.212	0.040 ± 0.035	−0.206 ± 0.309
Radio-loud	$\log M_{\rm BH}$	z, $R_{\rm EDD}$, $\lambda_{\rm rf}$	−0.220	0.432	−0.180	−0.052 ± 0.052	0.600 ± 0.477

Notes:
[1] The radio-quiet (radio-loud) subsample contains quasars with radio loudness smaller (larger) than 10. [2] The parameter on which the dependence of variability is to be considered. [3] Parameters which are restricted in small ranges to exclude their influences on variability, denoted by $x1$, $x2$ and $x3$. [4]−[5] $r1$ is the median value of Spearman Rank Correlation Coefficients in all the qualified small data sets, while p is the median value of the significance of its deviation from 0. [6] $r2$ is the median value of Pearson Product Correlation Coefficient, indicating the strength of linear correlations. [7]−[8] b is the median slope of the linear fitting for the dependence of the variability amplitude on the parameter denoted in Column and a is the median y-axis intercept of the linear fit.

2. Overview

Statistical results. The median values for the relationships between V and different quasar parameters are summarized in Table 1.

Implications of the Standard Accretion Disk model. Based on the Shakura–Sunyaev model (Shakura & Sunyaev 1973, Li *et al.* 2008), assuming the change of accretion rate as the origin of quasar variability, we calculate spectra for different black hole masses and accretion rates. After convolving with the SDSS filter response function, we convert the flux to the SDSS AB magnitude $A(M_{\rm BH}, \dot{m})$. Assuming the change of $\dot{m}$ is $x\dot{m}$, we adopt $V = A(M_{\rm BH}, \dot{m}) - A(M_{\rm BH}, (1+x)\dot{m})$ as variability indicators. The predicted relationships between V and the quasar parameters have good agreements with the statistical results.

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