Multiwavelength AGN Surveys and Studies
Proceedings IAU Symposium No. 304, 2013
A. M. Mickaelian & D. B. Sanders, eds.

doi:10.1017/S1743921314003962

Further determination of interband lags between variations in B, V, R, and I bands in active galactic nuclei

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Abstract. New estimates of the interband lags between variations in the B band and variations in the V, R, and I bands for three active galactic nuclei (AGNs) are present. In contrast to the previous study by Sergeev *et al.* (2005), the effect of the contribution of the broad lines to the bands is taken into account.

Keywords. galaxies: active, galaxies: nuclei, galaxies: photometry, galaxies: Seyfert

1. Introduction

To explain the observed correlation between flux variations in the X-ray, ultraviolet, and optical wavelengths in AGNs, the reprocessing model has been proposed. In this model, the accretion disk irradiates not only due to viscous friction, but also due to X-ray heating. The model has received some observational support from comparison of flux variations at various wavelengths (e.g., Collier *et al.* 1998, 1999; Sergeev *et al.* 2005).

2. Observations and Method

Photometric observations and instrumental setup are described in details in Sergeev *et al.* (2005). The filter wheel contains a set of B, V, R, $R1$, and I filters, where the filter designated $R1$ closely resembles the Cousins I filter, while the other filters closely resemble the standard Johnson filters. I have used Crimean data obtained as a part of the international monitoring campaign over a 140-day span beginning in 2010 August (Grier *et al.* 2012). To subtract broad-line fluxes from the photometric light curves of AGNs, I have used the Crimean optical spectra of these AGNs. I have separated broad emission lines from the continuum. The net broad-line spectra were then passed through the transparency curves of our filters to simulate magnitudes of the broad emission lines. The broad-line spectrum consists of the following lines: Balmer lines (usually most bright), He II, He I, and Fe II multiplets. To account for the contribution of the bright H_α line to the red filters, when the H_α region spectra were unavailable, it was assumed that the H_α line profile is identical to the H_β line profile with the Balmer decrement of 3.

3. Results and Summary

I have analyzed the three AGNs: 3C 120, Mrk 6, and Mrk 1513. The light curves of the Mrk 6 nucleus are shown in Fig. 1. The interpolation cross-correlation functions (ICCF) have been computed between variations in the B filters and variations in other filters. I have measured a lag at the ICCF peak (τ_{peak}) and the ICCF centroid (τ_{cent}). The cross-correlation results are present in Table 1 (both original data and after subtraction the

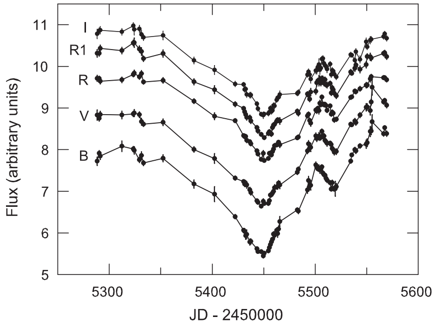

Figure 1. Light curves of the Mrk 6 nucleus. The flux units for each filter are arbitrary.

Table 1. Interband cross-correlation results

Object Name	Filter	τ_{peak} (days)	τ_{peak} conf. interval -3σ	$+3\sigma$	τ_{cent} (days)	τ_{cent} conf. interval -3σ	$+3\sigma$	r_{max}
			broad-line contribution is NOT subtracted:					
3C 120	V	−0.39	−3.34	+2.41	−0.45	−2.95	+1.75	0.9917
3C 120	R	+1.62	−1.68	+6.89	+2.31	−0.31	+5.07	0.9783
3C 120	R1	+1.44	−2.46	+5.54	+1.79	−1.32	+4.43	0.9766
3C 120	I	+1.40	−2.45	+6.40	+1.89	−1.13	+4.86	0.9784
Mrk 6	V	+0.40	−1.63	+3.22	+0.99	−1.40	+3.29	0.9937
Mrk 6	R	+4.57	+0.45	+7.33	+5.26	+2.79	+7.84	0.9738
Mrk 6	R1	+3.32	−0.34	+8.15	+5.26	+2.85	+8.26	0.9654
Mrk 6	I	+5.75	+0.38	+13.0	+6.18	+2.95	+12.0	0.9522
Mrk 1513	V	+0.48	−2.44	+3.40	−0.20	−4.44	+3.31	0.9821
Mrk 1513	R	+1.48	−1.34	+6.47	+2.38	−1.08	+5.57	0.9784
Mrk 1513	R1	+4.43	−1.33	+8.55	+4.77	−0.99	+8.06	0.9623
Mrk 1513	I	+3.41	−1.46	+11.3	+4.94	+1.04	+8.58	0.9491
			broad-line contribution is subtracted:					
3C 120	V	+0.53	−1.66	+3.50	+1.08	−1.38	+3.09	0.9850
3C 120	R	+1.52	−0.90	+5.71	+2.41	+0.06	+4.80	0.9723
Mrk 6	V	+0.38	−1.62	+3.27	+0.95	−1.49	+3.42	0.9934
Mrk 6	R	+3.33	−0.90	+6.40	+4.09	+1.35	+11.6	0.9628
Mrk 1513	V	+0.49	−1.67	+2.62	+0.72	−1.38	+3.53	0.9775
Mrk 1513	R	+1.47	−0.71	+4.80	+2.75	−0.81	+5.60	0.9694
Mrk 1513	R1	+3.52	−0.55	+8.57	+5.60	+0.55	+8.46	0.9474
Mrk 1513	I	+3.41	−0.72	+15.4	+5.87	+2.27	+12.6	0.9356

broad-line contribution). Also given are maximum correlation coefficient r_{max} and $\pm 3\sigma$ confidence intervals for the lag. A positive lag means that the B-filter flux varies first, while other filters follow it with some delay. The interband lags are positive at more than 3σ confidence in several cases and there is a tendency for the lag to be greater for more red filters. It is obvious that the broad-line contribution affects the lag measurements, although not catastrophically in most cases. The lag increases if the relative broad-line contribution to the B band is greater than that for a given band and vice versa.

I confirm our previous result (Sergeev *et al.* 2005): the variations at the V, R, and I bands lag behind those at the B band and the lag is higher for longer wavelengths.

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