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TIMING ANALYSIS OF LIGHT CURVES OF 3C390.3

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Abstract. The timing analysis of light curves of astrophysical objects could reveal characteristic timescales which in turn describe physics of these objects. We applied cross correlation analysis in order to find the timescale of the lag between the Hβ line and continuum using the observations from the long-term spectral monitoring.

1. INTRODUCTION

A long-term spectral monitoring of some active galactic nuclei (AGN) has revealed a time lag in the response of the broad emission lines relative to the flux changes in the continuum. This lag depends on the size, geometry, and physical conditions of the broad line region (BLR). Thus, the search for correlations between the nuclear continuum changes and flux variations in the broad emission lines can reveal the structure of the BLR (see e.g., Peterson 1993, and reference therein). During the past decade, the study of the BLR in some objects has achieved considerable success, mainly because of the increasing number of coordinated multiwavelength monitoring campaigns through the international "AGN Watch" program (see e.g., Peterson 1999). Most of the objects, included in the AGN Watch, are radio-quiet Sy1 galaxies and only one, 3C 390.3 (z=0.0561), is a well known broad-line radio galaxy. It is a powerful double-lobed FRII radio-galaxy with a relatively strong compact core. The VLBI observations at 5 GHz show evidence of the superluminal motion (with v/c nearly 4) in its parsec-scale jet (Alef et al. 1996).

2. OBSERVATIONS

Spectra of 3C 390.3 (during 158 nights) were taken with the 6m and 1m telescopes of the SAO RAS (Russia, 1995–2007) and with INAOE's 2.1m telescope of the "Guillermo Haro Observatory" (GHO) at Cananea, Sonora, Mexico (1998–2007). They were acquired using long-slit spectrographs, equipped with CCD detector arrays. The typical wavelength interval covered was from 4000Å to 7500Å, the spectral resolution varied between 5 and 15 Å, and the S/N ratio was > 50 in the continuum near Hα and Hβ. The more details about the observation and data reduction can be found in Shapovalova et al. (2010).

3. CROSS CORRELATION ANALYSIS

To estimate the size and structure of the BLR, one can derive the cross-correlation function (CCF) of the continuum light curve with the emission-line light curves. There are several ways to construct a CCF. Therefore, we cross-correlated the 5100 Å continuum light curve with both the Hα and Hβ line (and their parts) light curves using two methods: (i) the z-transformed discrete correlation function (ZDCF) method (Alexander 1997), and (ii) the interpolation cross-correlation function method (ICCF) (Bischof &Kollatschny 1999). Using this ZDCF, we obtained a lag of 96 days (error range is (+28,−47) days) and a correlation coefficient of 0.92±0.02 between the continuum and Hβ. The lags and CCF coefficients are given in Table 1. In case of the Hα line, the CCF is affected by noise because of the small amount of observational data, and it is difficult to reliably determine the lag. Also, we applied the ICCF method to cross-correlate the flux of the continuum with both the Hβ and Hα fluxes, and found lags of 97±17 days (CCF=0.95) for Hβ and 270±150 days (CCF=0.84) for Hα, which agree with the ZDCF analysis. Both methods indicate that the lag between the continuum and Hβ flux is around 95 days. For the Hα line, the ICCF method is also not reliable (because of the small amount of observations). To confirm the results obtained for Hα we compiled centroids for Hα (see Table 1) and measured a lag of 127 ± 18 days, which is closer to the larger value obtained from ZDCF.

We also correlated the continuum and line parts, as well as the line parts with the other line parts, finding that the lag in the continuum vs. Hβ line parts is 96 (error range (+47,−28) days) in all cases (the CCF is larger than 0.9). This and a short lag in the Hβ line part -line part lag (6^{+36}_{-6} days - practically around zero within the errorbars) indicate that total line responses to the continuum vary at the same time. There is no significant lag between the blue and red Hβ line parts, when we consider only blue and red part, and in the second case when we consider the blue, central and red part.

Table 1. The time lag and CCF coefficient for the continuum and Hβ and Hα line (total line and parts) using ZDCF method. The centroids of lags are also given.

pair I	pair II	lag (ZDCF) (days)	ZDCF	lag (centroid) (days)	90% Max_{ZDCF}
F_{cnt}	$F(H\beta)_{tot}$	96^{+28}_{-47}	$0.92^{+0.02}_{-0.02}$	93^{+20}_{-18}	0.83
F_{cnt}	$F(H\beta)_{blue}$	96^{+47}_{-28}	$0.92^{+0.02}_{-0.02}$	71^{+34}_{-26}	0.83
F_{cnt}	$F(H\beta)_{red}$	96^{+47}_{-28}	$0.92^{+0.02}_{-0.02}$	70^{+34}_{-26}	0.83
F_{cnt}	$F(H\beta)_{core}$	96^{+47}_{-28}	$0.91^{+0.02}_{-0.02}$	72^{+33}_{-26}	0.82
$F(H\beta)_{blue}$	$F(H\beta)_{red}$	6^{+36}_{-6}	$0.96^{+0.01}_{-0.01}$	-5^{+28}_{-30}	0.87
$F(H\beta)_{blue}$	$F(H\beta)_{core}$	6^{+36}_{-6}	$0.94^{+0.01}_{-0.01}$	-4^{+28}_{-29}	0.85
F_{cnt}	$F(H\alpha)_{tot}$	24^{+7}_{-5}	$0.90^{+0.05}_{-0.07}$	127^{+18}_{-18}	0.81
		(151^{+20}_{-9})	$0.90(^{+0.05}_{-0.06})$		
F_{cnt}	$F(H\alpha)_{blue}$	64^{+26}_{-21}	$0.92^{+0.04}_{-0.06}$	76^{+14}_{-13}	0.83
		(175^{+25}_{-12})	$(0.90^{+0.05}_{-0.06})$		
F_{cnt}	$F(H\alpha)_{red}$	23^{+7}_{-5}	$0.87^{+0.07}_{-0.09}$	75^{+14}_{-14}	0.79
		(175^{+24}_{-12})	$(0.81^{+0.08}_{-0.10})$		
F_{cnt}	$F(H\alpha)_{core}$	64^{+26}_{-21}	$0.90^{+0.06}_{-0.07}$	76^{+14}_{-13}	0.81
		(175^{+25}_{-12})	$(0.81^{+0.08}_{-0.10})$		
$F(H\alpha)_{blue}$	$F(H\alpha)_{red}$	23^{+7}_{-5}	$0.95^{+0.03}_{-0.04}$	10^{+8}_{-9}	0.85
		(-1^{+1}_{-8})	$(0.93^{+0.02}_{-0.03})$		
$F(H\alpha)_{blue}$	$F(H\alpha)_{core}$	23^{+7}_{-5}	$0.95^{+0.02}_{-0.03}$	50^{+13}_{-11}	0.86
		(-1^{+1}_{-8})	$(0.93^{+0.02}_{-0.03})$		

For Hα, Table 1 shows that there may be the same lag between the blue and red/central part, around 23 days. However, since for Hα there are fewer data available for the calculation than for Hβ, as well as that there is one peak around zero (with a slightly smaller CCF value; see values in brackets in Table 1), this should be interpreted with care. In Table 1, the correlations between the continuum flux and either Hα or Hβ give different values, indicating different sizes of the Hα and Hβ emission regions. The lag measured for Hβ is nearly 95 days, while for Hα it is closer to 100 days. In addition, the coefficient of variability (see Table 5 in Shapovalova et al. 2010) is slightly higher for Hβ than Hα, implying that the Hβ emitting region may be more compact than that of Hα.

4. CONCLUSION

The CCF of the continuum and Hβ broad emission line fluxes shows a lag about 95 days, as in both Shapovalova et al. (2001) and Sergeev et al. (2002, lag nearly 89 days). There is no significant lag between both the blue and red wings and the core, which is indicative of predominantly circular motions in the BLR of 3C390.3 and a disk-like geometry. For Hα, we found a lag of around 120 days. This difference in lags as well as in the width of Hα and Hβ may imply that there is some stratification in the BLR (disk) of 3C 390.3.

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