## Intra-day Simultaneous Optical Monitoring of S5 0716+714

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Abstract
We present the result of simultaneous optical multi-color observation of BL Lac object $0716+714$ in November 2014 and February 2016. The intraday variability (IDV) varies from 0.04 to 0.3 mag . Both achromatic and bluer-when-brighter (BWB) color behaviours were detected. A probable quasi-periodic oscillation overlapping on a significant flare was also observed. We used the interpolated cross-correlation function to calculate time lags between light curves in different bands. Variations in B and R lagging behind that in I band was found, which correspond with anti-clockwise loops on the color-magnitude diagrams. Such an optical time delay can be interpreted by acceleration and cooling process of electrons in jet of the blazar.

## Introduction

S5 $0716+714$ is a well-studied BL Lac object with violet variability at different wavelengths from radio to $\gamma$-ray and on different time scales from several minutes to decades.
The color behavior and the spectra evolution of blazars are basic issues to constraint physical process in jet. Loop-like path in color-magnitude diagram can be caused by acceleration and cooling process of particles in jet (e.g. Chiaberge \& Ghisellini 1999, Kirk et al. 1998). It also conducts time lags between different optical bands. Aiming to find these lags precisely, we monitored it with high temporal resolution.

## Observation \& Light Curve

We performed observation with three telescopes in Xinglong Station of the National Astronomical Observatories of China (NAOC) from 1st November to 3rd November in 2014 (JD 2456963 to 2456965) and from 16th February to 17 th February in 2016 (JD 2457435 to 2457436). The light curves are ploted in Figure.1.


Figure 1: Light curves of S5 0715+714 in Nov. 2014 (left panel) and in Feb 2016 (right panel).

On JD 2456965, a ~20 min QPO is detected in Lomb-Scargle periodogram. The theoretical red noise spectrm and confidence levels are calculated by REDFIT (Schulz \& Mudelsee, 2002).


Figure 2: Left panel: light curve in the B band on JD 2456965; Right panel: Lomb-Scargle periodograms of light curve in the left panel.

## Cross-Correlation

We carried out cross-correlation using interpolated corss-correlation function to calculate time lags. The uncertainty is estimated by flux randomization/random subset selection method. See Peterson et al. (2004) for more details. The results are listed in Table. 1

Table 1: Results of cross-correlation.

| JD | $\mathrm{B}-\mathrm{R}$ | $\mathrm{R}-\mathrm{I}$ | $\mathrm{B}-\mathrm{I}$ |
| :---: | :---: | :---: | :---: |
| 2456963 | $-3.54 \pm 5.97$ | $-5.70 \pm 6.99$ | $-9.17 \pm 8.27$ |
| 2456964 | $1.00 \pm 1.91$ | $-0.43 \pm 3.00$ | $-0.31 \pm 2.94$ |
| 2456965 | $0.34 \pm 0.50$ | $1.31 \pm 0.60$ | $1.45 \pm 0.51$ |
|  | $\mathrm{~B}-\mathrm{V}$ | $\mathrm{V}-\mathrm{R}$ | $\mathrm{B}-\mathrm{R}$ |
| 2457435 | $1.66 \pm 6.91$ | $1.61 \pm 5.83$ | $-1.48 \pm 8.26$ |
| 2457436 | $-11.05 \pm 14.16$ | $-2.36 \pm 12.34$ | $-13.93 \pm 13.55$ |

## Color Behavior

- On JD 2456963 and 2457437 , all six color-magnitude diagrams exhibit achromatic color behavior.
- On JD 2456964 and 2457437, marginal BWB color variation was shown.
- Significant BWB trends can be found in diagrams on JD 2456965, along with an anti-clockwise loop that correspond with time lags observed between different bands.














Figure 3: Color-magnitude diagrams for each separate night.

## CONCLUSION

1. Both achromatic and BWB chromatism were discovered in our observation.
2. Sinusoidal light curves were observed on JD 2456963 with achromatic variation and no time lags between different bands. A geometric effect model can interpret it.
3. Significant BWB trend, QPOs and plausible inter-band lags were detected in the drastic variation on JD 2456965.

## Reference

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