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MULTICOLOR NEAR-INFRARED INTRA-DAY AND SHORT-TERM VARIABILITY OF THE BLAZAR S5 0716+714

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ABSTRACT

In this paper, we report results of our near-infrared (NIR) photometric variability studies of the BL Lacertae (BL Lac) object S5 0716+714. NIR photometric observations were spread over seven nights during our observing run on 2007 April 2–9 at the 1.8 m telescope equipped with the Korea Astronomy and Space Science Institute Near-Infrared Camera System and J, H, and K_s filters at Bohyunsan Optical Astronomy Observatory, South Korea. We searched for intra-day variability (IDV), short-term variability, and color variability in the BL Lac object. We have not detected any genuine IDV in any of the J, H, and K_s passbands in our observing run. Significant short-term variabilities ~32.6%, 20.5% and 18.2% have been detected in the J, H, and K_s passbands, respectively, and ~11.9% in $(J - H)$ color.

Key words: BL Lacertae objects: individual (S5 0716+714) – galaxies: active – infrared: galaxies

Online-only material: color figures

1. INTRODUCTION

Blazars constitute a small subclass of the most enigmatic class of radio-loud active galactic nuclei (AGNs) consisting of BL Lacertae (BL Lac) objects and flat spectrum radio quasars (FSRQs). BL Lacs show largely featureless optical continuum. Blazars exhibit strong flux variability at all wavelengths of the complete electromagnetic (EM) spectrum, strong polarization (>3%) from radio to optical wavelengths, usually core-dominated radio structures, and predominantly nonthermal radiation at all wavelengths. In a unified model of radio-loud AGNs based on the angle between the line of sight and the emitted jet from the source, blazar jets make an angle of less than 10° from the line of sight (Urry & Padovani 1995).

From the study of the spectral energy distributions (SEDs) of blazars, it is found that blazars' SEDs have two peaks (Fossati et al. 1998; Ghisellini et al. 1998). The first component peaks at near-infrared (NIR)/optical in low-energy-peaked blazars (LBLs) and at UV/X-rays in high-energy-peaked blazars (HBLs). The second component peaks at GeV energies in LBLs and at TeV energies in HBLs. The EM emission is dominated by synchrotron component at low energies and at high energies probably by the inverse Compton (IC) component (Coppi 1999; Sikora & Madejski 2001; Krawczynski 2004).

From observations of blazars, it is known that they vary on diverse timescales ranging from a few minutes to several years. Blazars' variability can be broadly divided into three classes—intra-day variability (IDV; or intra-night variability or microvariability), short-term variability, and long-term variability. Variations in the flux of a few tenths of a magnitude over the course of a day or less is often known as IDV (Wagner & Witzel 1995). Short- and long-term variabilities can have timescales from a few weeks to several months and several months to years, respectively.

The first convincing optical IDV in a blazar was reported by Miller et al. (1989), and since then variability of blazars on diverse timescales in radio-to-optical bands has been studied extensively and results have been reported in a large number of papers (e.g., Carini 1990; Mead et al. 1990; Takalo et al. 1992, 1996; Heidt & Wagner 1996; Sillanpää et al. 1996a, 1996b; Bai et al. 1998, 1999; Fan et al. 1998, 2002, 2007; Xie et al. 2002; Ciprini et al. 2003, 2007; Gupta et al. 2004, 2008a, 2008b; Stalin et al. 2005, and references therein). In a recent paper, Gupta & Joshi (2005) have done statistical analysis of the occurrence of optical IDV in different classes of AGNs. They divided their sample of 113 optical light curves of blazars in three different time durations and found that 64%(18/28), 63%(29/46), and 82%(32/39) blazars show IDV if observed for $\leqslant$3 hr, 3 hr to $\leqslant$ 6 hr, and > 6 hr, respectively.

S5 0716+714 ($\alpha_{2000.0}$ = 07:21:53.4, $\delta_{2000.0}$ = +71:20:36.4) is one of the brightest BL Lac object which has featureless optical continuum. The nondetection of its host galaxy first sets a lower limit of redshift $z > 0.3$ (Wagner et al. 1996), and then $z > 0.52$ (Sbarufatti et al. 2005). Very recently, Nilsson et al. (2008) have claimed that its host galaxy detection produces a "standard candle" value of $z = 0.31 \pm 0.08$. Wagner & Witzel (1995) reported that the duty cycle of the source is one which implies that the source is almost always in the active state. The variability of S5 0716+714 has been studied in the complete EM spectrum on all timescales (e.g., Raiteri et al. 2003; Gupta et al. 2008b, and references therein). Large and variable optical polarization in the source has been reported (Takalo et al. 1994; Fan et al. 1997; Impey et al. 2000). Since 1994, this source has been extensively monitored in optical bands. There are five major optical outbursts reported in the source: at the beginning of 1995, in late 1997, in the fall of 2001, in 2004 March, and in the beginning of 2007 (Raiteri et al. 2003; Foschini et al. 2006; Gupta et al. 2008b). These five outbursts give a possible period of long-term variability of ~3.0 ± 0.3 years.

Compared with radio and optical bands, there are only a few attempts to search for NIR flux variability on diverse timescales in blazars (e.g., Mead et al. 1990; Takalo et al. 1992; Gupta et al. 2004; Hagen-Thorn et al. 2006, and references therein). Since blazars emit radiation in the complete EM spectrum, they are ideal candidates for multiwavelength observations. However, due to either the unavailability of good quality NIR detectors or the unavailability of low humidity observing sites at several 1–2 m class NIR/optical telescopes around the world, there was no focused effort to search for NIR flux variability in LBLs in which SED synchrotron component peaks in NIR/optical bands. Now we have an excellent opportunity to carry out such observations from the Bohyunsan Optical Astronomy Observatory (BOAO), South Korea, which has a 1.8 m telescope and is equipped with the Korea Astronomy and Space Science Institute Near-Infrared Camera System (KASINICS; Moon et al. 2008). We have recently started our long-term pilot project to search for flux variability on diverse timescales in LBLs. Our present and future planned observations will fill the gap between radio and optical bands and will give deep insight into the important and less-studied NIR flux variability properties of LBLs. Simultaneous radio to gamma-ray observations will be useful in detecting the synchrotron and IC component peaks of LBLs from the SEDs and will be useful in understanding the emission mechanism of LBLs in the complete EM spectrum. With this motivation, we recently carried out J, H, and K_s band photometric observations of our first target, the BL Lac object S5 0716+714, which is an LBL, over seven observing nights during 2007 April 2–9.

The paper is organized as follows: Section 2 describes observations and data reduction methods, in Section 3 we mention our results, and the discussions and conclusions of the present work are reported in Section 4.

2. OBSERVATIONS AND DATA REDUCTION

The time-series observations of S5 0716+714 were carried out in the J, H, and K_s bands during 2007 April 2–9 using KASINICS mounted at the 1.8 m telescope of BOAO in South Korea. On April 4, observations were made only in the J and K_s bands. The on-source integration time in each band was 120 s throughout the observations except 60 s on April 4. The KASINICS has a field of view of $\sim 3.3 \times 3.3$ arcmin^2 with a 512×512 InSb array ALADDIN III Quadrant. Image frames were obtained in four dithered positions, offset by ≈ 15 arcsec. In all image frames of S5 0716+714, two standard stars, Star 3 and Star 5 of Villata et al. (1998) were always present.

Each image frame was processed to subtract the dark, to correct the pixel-to-pixel inhomogeneity (flat fielding), and to remove the bad pixels and cosmic rays. In order to remove the sky background, we subtracted another dithered image at a different position from an object image frame. Then four dithered images were aligned and average-combined to improve the signal-to-noise ratio (S/N). Instrumental magnitudes of the standard stars and the blazar in the processed image frames were measured by the aperture photometry. Data reductions and deriving the instrumental magnitudes were performed using standard routines in IRAF[4] (Image Reduction and Analysis Facility) software. Additional C programs were developed locally for automated data processing.

Since the object and the standard stars were observed in the same image frame, no correction for atmospheric extinction was done. Two standard stars in the blazar field were used to check the nonvariable characteristics of standard stars and finally one standard star (Star 3) was used to calibrate the instrumental magnitudes of the blazar S5 0716+714. The reliability of the photometry is verified by differential magnitudes of standard stars (Star 5 − Star 3). The results remain consistent throughout the observations within 1σ of 0.021, 0.028, and 0.028 in J, H, and K_s bands, respectively.

3. RESULTS

3.1. Variability Detection Criterion

Time variability of the blazar S5 0716+714 is investigated by using the parameter C (Romero et al. 1999) defined as the average of C_1 and C_2:

$$C_1 = \frac{\sigma(\mathrm{BL} - \mathrm{Star\,A})}{\sigma(\mathrm{Star\,A} - \mathrm{Star\,B})} \quad \text{and} \quad C_2 = \frac{\sigma(\mathrm{BL} - \mathrm{Star\,B})}{\sigma(\mathrm{Star\,A} - \mathrm{Star\,B})}. \tag{1}$$

Using aperture photometry of the blazar and two standard stars in the blazar field, we determined the differential instrumental magnitude of the blazar − standard star A, the blazar − standard star B, and standard star A − standard star B. We determined observational scatter from the blazar − standard star A (σ (BL − Star A)), the blazar standard star B (σ (BL − Star B)), and standard star A − standard star B (σ (Star A − Star B)).

If $C > 2.57$, the confidence limit of variability is 99%. The typical uncertainty level in our calculation of C parameter itself is 10%–20%. Here, we used Stars 5 and 3 of Villata et al. (1998) as Star A and Star B, respectively. J, H, and K_s magnitude of these standard stars are taken from the Two Micron All Sky Survey (2MASS) catalog[5] (Skrutskie et al. 2006). Final calibration of S5 0716+714 data is done by Star B (Star 3). The photometric software in IRAF does not give the actual internal error of brightness but it gives photon noise. The internal photometric errors of brightness for each J, H, and K_s band are estimated using an artificial add star experiment as described by Stetson (1987). We found that the standard deviation (σ) in each J, H, and K_s band is ~ 1.5 times larger than the typical photon noise. So, the typical photometric error in each J, H, and K_s band is ~ 0.01 mag.

3.2. Intra-Day Variability

Js passband. We observed the blazar S5 0716+714 on 2007 April 2, 3, 4, 6, 7, 8, and 9 in the J passband. The light curves of the blazar (filled circles) and differential instrumental magnitude (star 5 − star 3; filled triangles) with different arbitrary offsets are displayed in different panels in the left column of Figure 1. Dates of observations are marked in the panels. We performed the IDV detection test described above by Equation (1), and obtained the values of C for 2007 April 2, 3, 4, 6, 7, 8, and 9 to be 0.50, 0.75, 0.64, 0.50, 1.04, 1.83, and 2.30, respectively (see Table 1), which confirms that the source has not shown genuine IDV on any night of our seven nights of observations in the J passband. Photometric data of the observing campaign in the J passband are reported in Table 2.

H passband. We observed the blazar S5 0716+714 on 2007 April 2, 3, 6, 7, 8, and 9 in the H passband. The light curves of the blazar (filled circles) and differential instrumental magnitude (star 5 − star 3; filled triangles) with different arbitrary offsets are displayed in different panels in the middle column of Figure 1. Dates of observations are marked in the panels. We performed the IDV detection test described above by

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[4] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[5] www.ipac.caltech.edu/2mass/

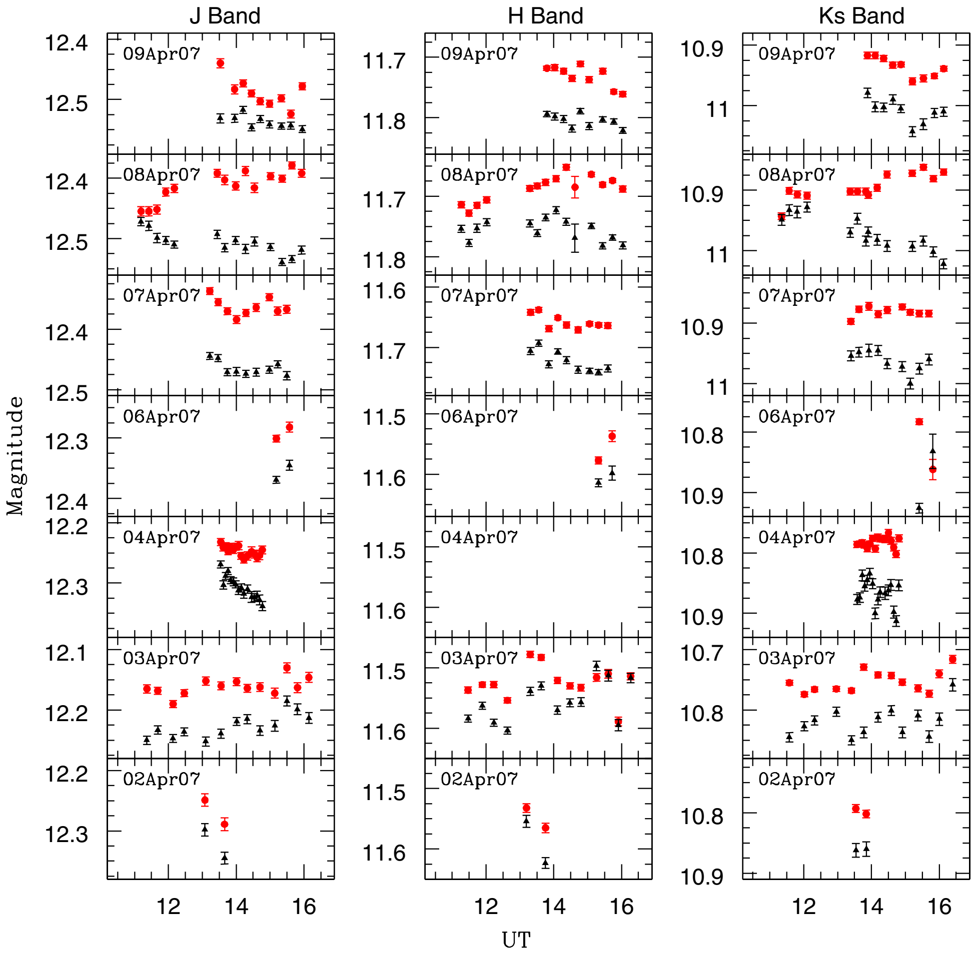

Figure 1. J-, H-, K_s-band light curves of S5 0716+718 (filled circles) and differential instrumental magnitude of standard stars (Star 5−Star 3; filled triangles) during the nights from 2007 April 2–9. Panels in the left, middle, and right columns show the light curves in the J, H, K_s bands, respectively. Standard stars differential light curve is offset for clarity by different arbitrary constants on all seven nights of observations.

(A color version of this figure is available in the online journal.)

Equation (1), and obtained the values of C for 2007 April 2, 3, 6, 7, 8, and 9 to be 0.49, 0.79, 2.05, 0.62, 1.22, and 1.32, respectively (Table 1), which confirms that the source has not shown genuine IDV on any night of our six nights of observations in the H passband. Photometric data of the observing campaign in the H passband are reported in Table 3.

K_s passband. We observed the blazar S5 0716+714 on 2007 April 2, 3, 4, 6, 7, 8, and 9 in the K_s passband. The light curves of the blazar (filled circles) and differential instrumental magnitude (star 5 − star 3; filled triangles) with different arbitrary offsets are displayed in different panels in the right column of Figure 1. The dates of observations are marked in the panels. We performed the IDV detection test described above by Equation (1), and obtained the values of C for 2007 April 2, 3, 4, 6, 7, 8, and 9 to be 7.00, 0.54, 0.63, 1.35, 0.78, 1.20, and 1.37, respectively (Table 1), which confirms that the source has not shown genuine IDV on 2007 April 3, 4, 6, 7, 8, and 9 in the K_s passband. The value of C on 2007 April 2 shows that the source has shown IDV but data points are only two, so its reliability is doubtful. Photometric data of the observing campaign in the K_s passband are reported in Table 4.

3.3. Short-Term Variability

In Figure 2, nightly averaged light curves of S5 0716+714 (standard mag) and comparison stars (differential instrumental mag of Stars 3 and 5) in J, H, K_s, $J-H$, and $H-K_s$ are plotted in the different panels from bottom to top, respectively. Here, we estimate the 99% confidence detection level of short-term variability using the variability detection test described in Section 3.1. For a specific date of observations, we have taken mean time of all the image frames in the J, H, and K_s bands and then converted the mean time in Julian Date (JD).

Short-term variability amplitude is calculated by using the following relation (Heidt & Wagner 1996):

$$A = 100 \times \sqrt{(A_{\max} - A_{\min})^2 - 2\sigma^2}(\%), \qquad (2)$$

where $A_{\max}$ and $A_{\min}$ are the maximum and minimum magnitudes in the calibrated light curve of the blazar in a complete observing run. σ is the averaged measurement error of the blazar light curve. Errors in our determination of A are less than 1%.

Js psassband. The short-term light curve of S5 0716+714 in the J passband is displayed in the bottom panel of Figure 2. The maximum variation noticed in the source is 0.325 mag (between its faintest level at 12.488 mag on JD 2454200.11894 and the brightest level at 12.163 mag on JD 2454194.08202). The value of C is calculated to be 7.05, which supports the existence of short-term variation in the source in J-band observations. We calculated short-term variability amplitude using Equation (2) and found that the source has varied ∼32.6%.

Table 1
Results of IDV of the Blazar S5 0716+714[a]

Date (dd.mm.yyyy)	Band	N	Diff. Mag BL − S_A	Diff. Mag BL − S_B	Diff. Mag $S_A - S_B$	Variable	C
02.04.2007	J	2	0.950 ± 0.028	−0.092 ± 0.005	1.042 ± 0.033	NV	0.50
	H	2	0.486 ± 0.023	−0.513 ± 0.025	0.999 ± 0.049	NV	0.49
	K_s	2	−0.181 ± 0.006	−1.182 ± 0.008	1.001 ± 0.001	PV	7.00
	$J - H$	2	0.464 ± 0.036	0.421 ± 0.025	0.043 ± 0.059	NV	0.52
	$H - K_s$	2	0.667 ± 0.024	0.669 ± 0.026	−0.002 ± 0.049	NV	0.51
03.04.2007	J	13	0.842 ± 0.014	−0.164 ± 0.016	1.007 ± 0.020	NV	0.75
	H	13	0.462 ± 0.028	−0.524 ± 0.026	0.985 ± 0.034	NV	0.79
	K_s	13	−0.225 ± 0.006	−1.245 ± 0.021	1.020 ± 0.025	NV	0.54
	$J - H$	13	0.380 ± 0.031	0.360 ± 0.031	0.022 ± 0.039	NV	0.79
	$H - K_s$	13	0.687 ± 0.029	0.721 ± 0.033	−0.035 ± 0.042	NV	0.74
04.04.2007	J	16	0.928 ± 0.008	−0.079 ± 0.015	1.007 ± 0.018	NV	0.64
	K_s	16	−0.195 ± 0.009	−1.191 ± 0.020	0.996 ± 0.023	NV	0.63
06.04.2007	J	2	0.973 ± 0.013	−0.045 ± 0.004	1.017 ± 0.017	NV	0.50
	H	2	0.494 ± 0.028	−0.492 ± 0.017	0.986 ± 0.011	NV	2.05
	K_s	2	−0.156 ± 0.056	−1.165 ± 0.122	1.009 ± 0.066	NV	1.35
	$J - H$	2	0.479 ± 0.031	0.447 ± 0.017	0.031 ± 0.020	NV	1.20
	$H - K_s$	2	0.650 ± 0.063	0.673 ± 0.123	−0.023 ± 0.067	NV	1.39
07.04.2007	J	9	1.044 ± 0.014	−0.001 ± 0.011	1.044 ± 0.012	NV	1.04
	H	9	0.595 ± 0.012	−0.438 ± 0.009	1.033 ± 0.017	NV	0.62
	K_s	9	−0.097 ± 0.008	−1.130 ± 0.020	1.033 ± 0.018	NV	0.78
	$J - H$	9	0.449 ± 0.018	0.437 ± 0.014	0.011 ± 0.021	NV	0.76
	$H - K_s$	9	0.692 ± 0.014	0.692 ± 0.022	0.000 ± 0.025	NV	0.72
08.04.2007	J	14	1.094 ± 0.025	0.077 ± 0.041	1.017 ± 0.018	NV	1.83
	H	14	0.625 ± 0.021	−0.391 ± 0.023	1.016 ± 0.018	NV	1.22
	K_s	14	−0.083 ± 0.021	−1.104 ± 0.046	1.021 ± 0.028	NV	1.20
	$J - H$	14	0.469 ± 0.033	0.468 ± 0.047	0.001 ± 0.025	NV	1.60
	$H - K_s$	14	0.708 ± 0.030	0.713 ± 0.051	−0.005 ± 0.033	NV	1.23
09.04.2007	J	9	1.169 ± 0.024	0.142 ± 0.022	1.027 ± 0.010	NV	2.30
	H	9	0.668 ± 0.018	−0.347 ± 0.011	1.015 ± 0.011	NV	1.32
	K_s	9	−0.042 ± 0.016	−1.080 ± 0.010	1.038 ± 0.019	NV	1.37
	$J - H$	9	0.501 ± 0.030	0.489 ± 0.025	0.012 ± 0.015	NV	1.83
	$H - K_s$	9	0.710 ± 0.024	0.733 ± 0.015	−0.023 ± 0.022	NV	0.89

Note. [a] V, PV, and NV in the variable column represent variable, possible variable, and nonvariable, respectively. *N* represents the number of data points.

H passband. The short-term light curve of S5 0716+714 in the H passband is displayed in the second panel from the bottom in Figure 2. The maximum variation noticed in the source is 0.206 mag (between its faintest level at 11.731 mag on JD 2454200.11894 and the brightest level at 11.525 mag on JD 2454194.08202). The parameter C is 4.14, which supports the existence of short-term variation in the source in H-band observations. We calculated short-term variability amplitude using Equation (2) and found that the source has varied ∼20.5%.

K_s passband. The short-term light curve of S5 0716+714 in the K_s passband is displayed in the third panel from the bottom in Figure 2. The maximum variation noticed in the source is 0.183 mag (between its faintest level at 10.936 mag on JD 2454200.11894 and the brightest level at 10.753 mag on JD 2454194.08202). The parameter C is 3.93, which supports the existence of short-term variation in the source in K_s-band observations. We calculated short-term variability amplitude using Equation (2) and found that the source has varied ∼18.2%.

$J - H$ color. The short-term light curve of S5 0716+714 in $J - H$ color is displayed in the second panel from the top in Figure 2. The maximum variation noticed in the source is 0.119 mag (between level at 0.757 mag on JD 2454200.11894 and at the level at 0.638 mag on JD 2454194.08202). The parameter C is 2.86, which supports the existence of short-term variation in $J - H$ color. We calculated short-term variability amplitude using Equation (2) and found that the source has varied ∼11.9%.

$H - K_s$ color. The short-term light curve of S5 0716+714 in $H - K_s$ color is displayed in the top panel in Figure 2. The maximum variation noticed in the source is 0.061 mag (between level at 0.795 mag on JD 2454200.11894 and at the level at 0.734 mag on JD 2454197.14597). The parameter C is 1.78. Therefore, no $H - K_s$ color variation in the source is detected in our observations.

3.4. *Spectral Energy Distribution*

Spectral behavior of the blazar S5 0716+714 in different nights of our observations is displayed by different symbols in Figure 3. S5 0716+714 is an LBL in which synchrotron component peaks in NIR/optical bands. The spectral behavior of the source in our seven nights observations indicates that the synchrotron component would peak at wavelengths shorter than our J band. Since there is no simultaneous data in radio and optical bands, we cannot determine the peak position.

The source was brighter on April 3 compared to April 2, then it became fainter day after day until our last observation on April 9. The SED data of each day are fitted by a power-law function and we obtained spectral indexes of −0.87, −0.76, −0.86, −0.88, −0.93, and −1.00 for April 2, 3, 6, 7, 8, and 9, respectively. The spectral index increases before the maximum brightness on April 3 and decreases after it down

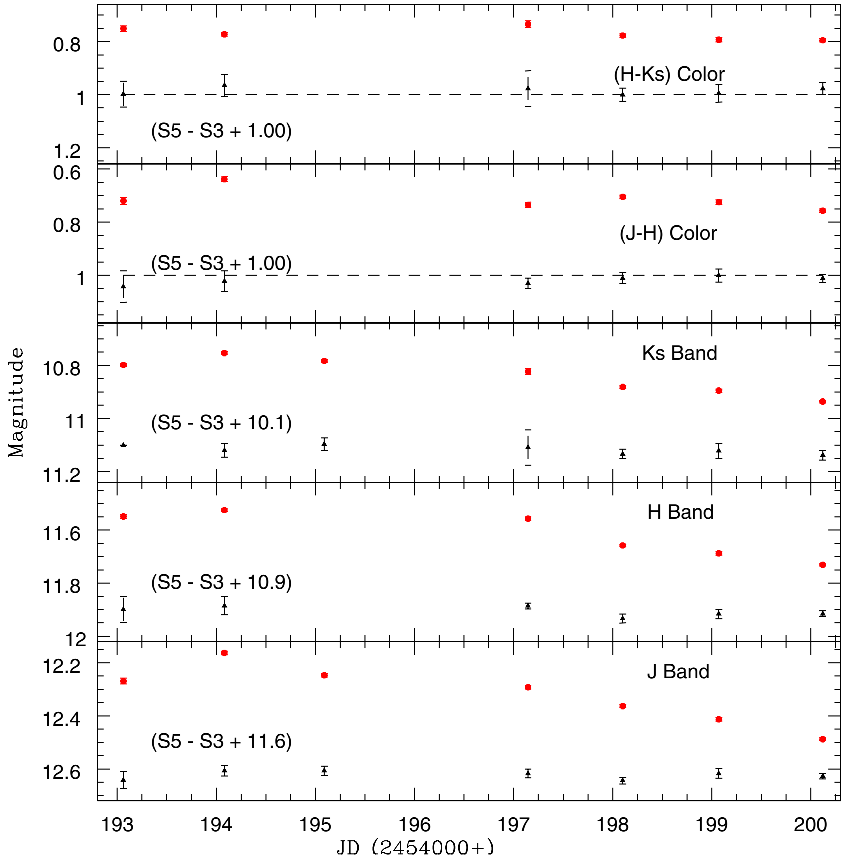

Figure 2. Daily-averaged light curves in the J, H, K_s, $J - H$, and $H - K_s$ of S5 0716+714 (filled circles) and differential instrumental magnitude of standard stars (Star 5−Star 3; filled triangles) during the nights of 2007 April 2–9 are plotted in the different panels from bottom to top, respectively. For clarity, the differential instrumental magnitude of standard stars (Star 5−Star 3) is offset by the amounts marked on the panels.

(A color version of this figure is available in the online journal.)

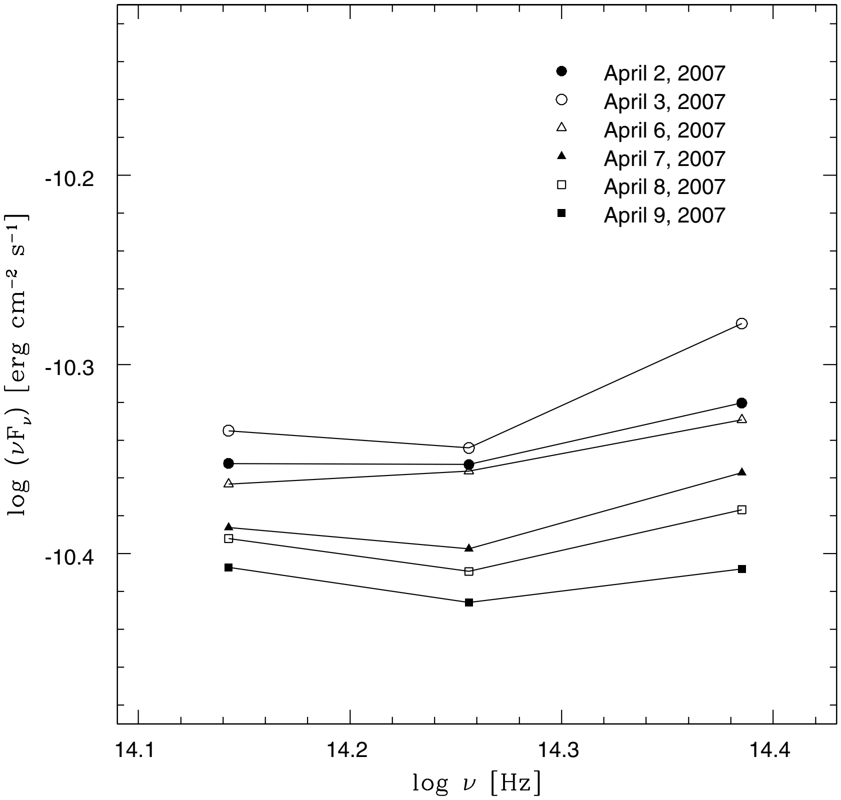

Figure 3. Spectral behavior of S5 0716+714 for six nights during 2007 April 2–9. Different symbols are used for different dates.

Table 2
J-Band Photometric Data of the Blazar S5 0716+714

Date (yyyy.mm.dd)	UT (hr)	Magnitude	Error
2007.04.02	13.0767	12.249	0.0103
2007.04.02	13.6577	12.289	0.0108
2007.04.03	11.3628	12.165	0.0067
2007.04.03	11.6856	12.168	0.0058
2007.04.03	12.1344	12.190	0.0058
2007.04.03	12.4653	12.172	0.0058
2007.04.03	13.1033	12.152	0.0067
2007.04.03	13.5543	12.160	0.0067
2007.04.03	14.0155	12.153	0.0067
2007.04.03	14.3276	12.164	0.0067
2007.04.03	14.7036	12.162	0.0072
2007.04.03	15.1420	12.172	0.0081
2007.04.03	15.5005	12.130	0.0081
2007.04.03	15.8084	12.163	0.0081
2007.04.03	16.1480	12.146	0.0081
2007.04.04	13.5451	12.232	0.0058
2007.04.04	13.6240	12.241	0.0058
2007.04.04	13.6928	12.239	0.0058
2007.04.04	13.7610	12.247	0.0058
2007.04.04	13.8381	12.240	0.0058
2007.04.04	13.9185	12.245	0.0058
2007.04.04	13.9874	12.240	0.0058
2007.04.04	14.0717	12.238	0.0067
2007.04.04	14.1499	12.255	0.0058
2007.04.04	14.2285	12.261	0.0058
2007.04.04	14.3353	12.255	0.0067
2007.04.04	14.4575	12.248	0.0081
2007.04.04	14.5378	12.252	0.0067
2007.04.04	14.6199	12.258	0.0067
2007.04.04	14.6928	12.254	0.0072
2007.04.04	14.7733	12.245	0.0067
2007.04.06	15.1859	12.301	0.0058
2007.04.06	15.5757	12.282	0.0081
2007.04.07	13.2219	12.337	0.0058
2007.04.07	13.4691	12.355	0.0058
2007.04.07	13.7392	12.370	0.0058
2007.04.07	14.0084	12.384	0.0067
2007.04.07	14.2890	12.373	0.0058
2007.04.07	14.5922	12.364	0.0067
2007.04.07	14.9806	12.347	0.0058
2007.04.07	15.2281	12.370	0.0067
2007.04.07	15.4945	12.367	0.0067
2007.04.08	11.1906	12.455	0.0076
2007.04.08	11.4216	12.455	0.0076
2007.04.08	11.6621	12.452	0.0076
2007.04.08	11.9226	12.423	0.0067
2007.04.08	12.1747	12.417	0.0067
2007.04.08	13.4435	12.392	0.0067
2007.04.08	13.6623	12.403	0.0076
2007.04.08	13.9838	12.413	0.0067
2007.04.08	14.2744	12.388	0.0076
2007.04.08	14.5426	12.416	0.0076
2007.04.08	15.0147	12.397	0.0058
2007.04.08	15.3563	12.401	0.0058
2007.04.08	15.6473	12.379	0.0058
2007.04.08	15.9339	12.392	0.0067
2007.04.09	13.5311	12.440	0.0076
2007.04.09	13.9564	12.483	0.0076
2007.04.09	14.2050	12.473	0.0058
2007.04.09	14.4568	12.490	0.0058
2007.04.09	14.7123	12.503	0.0058
2007.04.09	14.9869	12.507	0.0058
2007.04.09	15.3351	12.498	0.0058
2007.04.09	15.6168	12.524	0.0067
2007.04.09	15.9539	12.478	0.0058

Table 3
H-Band Photometric Data of the Blazar S5 0716+714

Date (yyyy.mm.dd)	UT (hr)	Magnitude	Error
2007.04.02	13.1916	11.532	0.0072
2007.04.02	13.7532	11.565	0.0081
2007.04.03	11.4691	11.537	0.0050
2007.04.03	11.8890	11.528	0.0042
2007.04.03	12.2291	11.528	0.0050
2007.04.03	12.6306	11.554	0.0042
2007.04.03	13.3047	11.478	0.0050
2007.04.03	13.6283	11.483	0.0050
2007.04.03	14.1066	11.521	0.0050
2007.04.03	14.4783	11.530	0.0050
2007.04.03	14.8032	11.533	0.0057
2007.04.03	15.2618	11.516	0.0064
2007.04.03	15.6085	11.510	0.0072
2007.04.03	15.9071	11.589	0.0071
2007.04.03	16.2718	11.514	0.0058
2007.04.06	15.3187	11.577	0.0057
2007.04.06	15.7229	11.537	0.0092
2007.04.07	13.3143	11.642	0.0050
2007.04.07	13.5536	11.638	0.0042
2007.04.07	13.8537	11.669	0.0050
2007.04.07	14.1191	11.651	0.0036
2007.04.07	14.3754	11.663	0.0050
2007.04.07	14.7183	11.671	0.0050
2007.04.07	15.0560	11.661	0.0036
2007.04.07	15.3214	11.663	0.0036
2007.04.07	15.5968	11.664	0.0050
2007.04.08	11.2673	11.714	0.0050
2007.04.08	11.4962	11.728	0.0050
2007.04.08	11.7304	11.715	0.0050
2007.04.08	12.0194	11.706	0.0050
2007.04.08	13.2942	11.687	0.0050
2007.04.08	13.5133	11.683	0.0050
2007.04.08	13.7582	11.677	0.0050
2007.04.08	14.0690	11.671	0.0050
2007.04.08	14.3667	11.652	0.0050
2007.04.08	14.6240	11.685	0.0180
2007.04.08	15.1095	11.664	0.0036
2007.04.08	15.4417	11.681	0.0042
2007.04.08	15.7355	11.674	0.0036
2007.04.08	16.0395	11.688	0.0050
2007.04.09	13.7980	11.718	0.0036
2007.04.09	14.0295	11.717	0.0050
2007.04.09	14.2900	11.723	0.0050
2007.04.09	14.5404	11.735	0.0050
2007.04.09	14.7849	11.711	0.0045
2007.04.09	15.0437	11.737	0.0050
2007.04.09	15.4440	11.723	0.0045
2007.04.09	15.7708	11.757	0.0036
2007.04.09	16.0364	11.761	0.0042

to -1. The change in spectral index between the maximum (-0.76) and the minimum (-1.00) is 0.24. This SED variation is owing to the larger flux variation at shorter wavelengths and is consistent with the short-term variability amplitudes reported in Section 3.3.

4. DISCUSSIONS AND CONCLUSIONS

From our multiband NIR observations of the blazar S5 0716+714 over seven observing nights in 2007 April, genuine IDV in any of J, H, and K_s is not detected. We noticed the existence of significant short-term flux variability in the blazar from our observations. The total short-term variation detected

Table 4

K_s-Band Photometric Data of the Blazar S5 0716+714

Date (yyyy.mm.dd)	UT (hr)	Magnitude	Error
2007.04.02	13.5410	10.793	0.0064
2007.04.02	13.8485	10.802	0.0064
2007.04.03	11.5766	10.755	0.0042
2007.04.03	12.0182	10.774	0.0042
2007.04.03	12.3193	10.766	0.0042
2007.04.03	12.9633	10.765	0.0042
2007.04.03	13.4103	10.768	0.0042
2007.04.03	13.7719	10.729	0.0050
2007.04.03	14.1940	10.742	0.0050
2007.04.03	14.5875	10.743	0.0050
2007.04.03	14.9135	10.754	0.0050
2007.04.03	15.3751	10.764	0.0057
2007.04.03	15.7039	10.773	0.0057
2007.04.03	16.0015	10.740	0.0064
2007.04.03	16.3985	10.716	0.0064
2007.04.04	13.5776	10.786	0.0050
2007.04.04	13.6598	10.785	0.0050
2007.04.04	13.7267	10.783	0.0050
2007.04.04	13.7985	10.787	0.0050
2007.04.04	13.8766	10.793	0.0050
2007.04.04	13.9520	10.785	0.0050
2007.04.04	14.0338	10.776	0.0050
2007.04.04	14.1124	10.793	0.0057
2007.04.04	14.1902	10.774	0.0050
2007.04.04	14.2609	10.777	0.0050
2007.04.04	14.4067	10.777	0.0064
2007.04.04	14.5010	10.767	0.0057
2007.04.04	14.5757	10.780	0.0057
2007.04.04	14.6575	10.791	0.0057
2007.04.04	14.7303	10.802	0.0057
2007.04.04	14.8092	10.776	0.0057
2007.04.06	15.4085	10.783	0.0050
2007.04.06	15.8120	10.862	0.0170
2007.04.07	13.3938	10.897	0.0050
2007.04.07	13.6301	10.877	0.0050
2007.04.07	13.9250	10.872	0.0064
2007.04.07	14.1989	10.885	0.0057
2007.04.07	14.4659	10.878	0.0057
2007.04.07	14.9096	10.873	0.0050
2007.04.07	15.1434	10.882	0.0050
2007.04.07	15.4132	10.884	0.0057
2007.04.07	15.6956	10.884	0.0057
2007.04.08	11.3472	10.943	0.0057
2007.04.08	11.5714	10.901	0.0057
2007.04.08	11.8080	10.907	0.0057
2007.04.08	12.0997	10.909	0.0057
2007.04.08	13.3733	10.902	0.0057
2007.04.08	13.5831	10.902	0.0057
2007.04.08	13.8364	10.902	0.0057
2007.04.08	14.1698	10.896	0.0057
2007.04.08	14.4618	10.874	0.0057
2007.04.08	13.9064	10.908	0.0057
2007.04.08	15.2049	10.872	0.0050
2007.04.08	15.5335	10.862	0.0050
2007.04.08	15.8278	10.881	0.0050
2007.04.08	16.1308	10.870	0.0050
2007.04.09	13.8834	10.917	0.0057
2007.04.09	14.1093	10.917	0.0057
2007.04.09	14.3602	10.922	0.0050
2007.04.09	14.6315	10.933	0.0050
2007.04.09	14.8720	10.932	0.0042
2007.04.09	15.2103	10.960	0.0057
2007.04.09	15.5332	10.955	0.0057
2007.04.09	15.8579	10.951	0.0042
2007.04.09	16.1326	10.939	0.0042

in our observations in the J, H, K_s passbands is ∼32.6%, 20.5% and 18.2%, respectively. Our data show significant variation in $J - H$ color (∼11.9%) but $H - K_s$ color variation was not detected. The difference in short-term variations in H and K_s passbands is only 2.3% which caused no genuine $H - K_s$ color variation. We have noticed a variable spectral index (ranging from -0.76 to -1.00) with a mean value of ~ -0.88 in our observations. The variable spectral index is mainly due to variation in the J-band flux. We also found correlated flux and spectral index (the higher the flux, the higher the spectral index). We observed the source in the post-outburst state. The outburst of the source was reported by Gupta et al. (2008b) in their 2007 January–February observations and they also noticed that in their March 2007 observations the source was becoming fainter than in 2007 January–February.

S5 0716+714 was the target of three simultaneous multiwavelength campaigns (Tagliaferri et al. 2003; Ostorero et al. 2006; Villata et al. 2008) and also several monitoring campaigns in single or two EM bands (e.g., radio-optical, optical, and optical-X-ray; Wagner et al. 1990; Quirrenbach et al. 1991; Sagar et al. 1999; Villata et al. 2000; Foschini et al. 2006, and references therein). It has shown radio and optical IDVs during all radio-to-optical campaigns (Heeschen et al. 1987; Wagner et al. 1990, 1996; Ghisellini et al. 1997; Sagar et al. 1999; Quirrenbach et al. 2000; Raiteri et al. 2003; Agudo et al. 2006; Gupta et al. 2008b, and references therein). It is the first IDV source in which simultaneous variations in radio and optical bands were detected which indicated a possible intrinsic origin of the observed IDV (Wagner et al. 1990; Quirrenbach et al. 1991). Very long baseline interferometry (VLBI) observations of the source over more than 20 years show a very compact source at centimeter wavelengths with an evidence of a core-dominated jet extending several tens of milliarcseconds to the north (Eckart et al. 1986, 1987; Witzel et al. 1988; Polatidis et al. 1995; Jorstad et al. 2001). The X-ray observations have shown strong variations with short flares (≈ 1000 s) detected with *ROSAT* (Cappi et al. 1994). The source was also detected in hard X-rays up to 60 keV when observed after the outburst state of 2000 (Tagliaferri et al. 2003). It has been detected by EGRET onboard the *Compton Gamma-Ray Observatory* (*CGRO*) at GeV energies with steep γ-ray spectrum (Hartman et al. 1999). But the soft γ-ray part of its SED is poorly known and the upper limit of the source detection in 3−10 MeV energy from the Imaging Compton Telescope (COMPTEL) was reported by Collmar (2006). An exceptional energy sampling data of the blazar was obtained in the simultaneous multiwavelength observing campaign in November 2003 (Ostorero et al. 2006). The source was very bright at radio frequencies and in a rather low optical state ($R = 14.17$–13.64). Significant short-term variability and IDV were detected in the radio bands. The source was not detected by INTEGRAL in the observing campaign but the upper limit of the source emission in 3–200 keV was estimated. On 2007 September, the source was detected in γ-rays by the recently launched satellite *Astrorivelatore Gamma a Immagini L'Eggero* (*AGILE*; Villata et al. 2008).

Several models have been developed to explain the IDV and short-term variability in radio-loud AGNs, viz., the shock-in-jet models, and accretion-disk-based models (e.g., Wagner & Witzel 1995; Urry & Padovani 1995; Ulrich et al. 1997, and references therein). For blazars in the outburst state, IDV and short-term variability are strongly supported by the jet-based models of radio-loud AGNs. In general, blazars emission in the outburst state is nonthermal Doppler-boosted emission from jets

(Blandford & Rees 1978; Marscher & Gear 1985; Marscher et al. 1992; Hughes et al. 1992). However, IDV and short-term variability of blazars in the low state can be explained by the models based on some kind of instability in the accretion disk (e.g., Mangalam & Wiita 1993; Chakrabarti & Wiita 1993).

Here, we rule out the possibility of emission from the accretion disk because it is expected to be relevant only in the source low state (the source was in the post-outburst period). The source was in the outburst state ∼2 months before the present observations (Gupta et al. 2008b). In the low state, jet emission is less dominant over the thermal emission from the accretion disk. According to the unified scheme of radio-loud AGNs, blazars are seen nearly face on, so any fluctuations on the accretion disk should produce a detectable change in the emission characteristics.

The observed short-term variability in the blazar S5 0716+714 is possibly explained by the jet-based model known as turbulent jet model. According to this model, Marscher et al. (1992) suggested that the Reynolds number in the relativistic jet should be very high which will cause turbulent jet plasma. The shock will impinge upon regions of slightly different magnetic field strengths, densities and velocities, so the observed flux is expected to vary. The timescales of this proposed type of variations are shorter and their amplitudes larger at higher frequencies. In the observations reported here, we obtained variability amplitudes of ∼32.6%, 20.5%, and 18.2% in the J, H, and K_s bands, respectively, implying larger variations at higher frequencies. The relation between flux variation amplitude and frequency is confirmed from the SED and color variation.

Since the duty cycle of the source is 1, we may expect to detect IDV. However, we have not detected any genuine IDV in our observations. It might be due to fewer data points and short durations of the observing runs during each night, hence in the future we plan to observe the source for a longer time each night. This will allow us to collect more data points and possibly to have a higher S/N in order to have higher sensitivity to possible genuine IDVs.

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