Determination of K4000 of potential blazar candidates among EGRET unidentified gamma-ray sources

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Abstract. Blazars are radio-loud Active Galactic Nuclei (AGN) with relativistic jets oriented towards the observer's line-of-sight. Based on their optical spectra, blazars may be classified as flat-spectrum radio quasars (FSRQs) or BL Lacs. FSRQs are more luminous blazars with both narrow and broad emission and absorption lines, while BL Lacs are less luminous and featureless. Recent studies show that blazars dominate ($\sim 93\%$) the already-identified EGRET sources (142), suggesting that among the unidentified sources (129) there could still be faint blazars. Due to the presence of a strong non-thermal component inside their jets, blazars are found to display a weaker depression at $\sim 4000\,\text{Å}$ (K4000 ≤ 0.4). In this study, we aimed at determining the K4000 break for a selected sample among the potential blazar candidates from unidentified EGRET sources to confirm their blazar nature. We used two blazar candidates, 3EG J1800-0146 and 3EG J1709-0817 associated with radio counterparts, J1802-0207 and J1713-0817, respectively. Their optical counterparts were obtained through spectroscopic observations using Robert Stobie spectrograph (RSS) at the Southern African Large Telescope (SALT) in South Africa. The observed Ca II H & K lines depression at $\sim 4000\,\text{Å}$ in spectra of these sources show a shallow depression, K4000 $= 0.35 \pm 0.02$ and 0.24 ± 0.01, respectively, suggesting that these sources are blazar candidates. Moreover, the redshifts z $= 0.165$ and 0.26 measured in their spectra confirm the extragalactic nature of these sources.

Keywords. line: identification, radiation mechanisms: non-thermal, techniques: spectroscopic, galaxies: active, galaxies: jets, galaxies: BL Lacertae objects.

1. Introduction

Different studies reveal that out of 271 sources detected by the Energetic Gamma-Ray Experiment Telescope (EGRET) during its mission, ~ 142 sources were identified and $\sim 93\%$ of them were associated with blazars (e.g., Hartman *et al.* 1999; Sowards-Emmerd *et al.* 2003; Nkundabakura & Meintjes 2012). It is assumed that among 129 ($\sim 48\%$) remaining unidentified EGRET sources, there could be still faint blazars in abundance. There have been efforts to try to identify blazars from the unidentified EGRET sources via their variability and spectral energy distribution (SED). This study joined this effort and aimed at determining the extent of non-thermal emissions from two potential blazar candidates selected among the remaining unidentified EGRET sources through the analysis of the strength of their Ca II H & K break at $\sim 4000\,\text{Å}$ (K4000). Blazars are a special class of AGN with a weaker Ca II contrast, i.e., K4000 $\leqslant 0.4$ (Marcha *et al.* 1996; Caccianiga *et al.* 1999; Landt *et al.* 2002), due to the contribution of the nuclear non-thermal component produced inside their jets, i.e., for blazars,
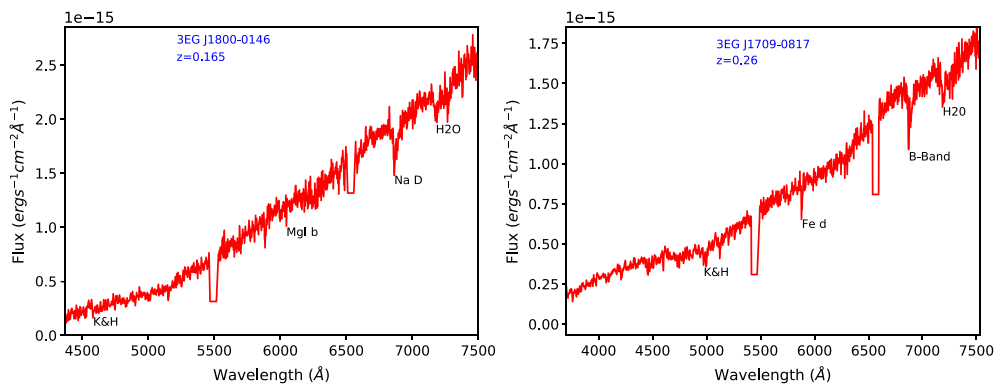
Figure 1. The left panel shows the spectrum of 3EG J1800-0146. The right panel shows the spectrum of 3EG J1709-0817.

this Ca II H & K break decreases as the non-thermal emission from jet increases and vice-versa. In fact, observations in optical, radio and X-rays show that the increase in the jet's luminosity leads to the decrease in the Ca II H & K break (Landt *et al.* 2002).

2. Data source and methods

The study used two blazar candidates (3EG J1800-0146 and 3EG J1709-0817) from a sample of 13 blazar candidates selected from Nkundabakura & Meintjes (2012) which were selected from the 3EG catalogue. The spectroscopic raw data were obtained at the Southern African Large Telescope (SALT) with RSS spectrograph. The raw data of the two sources were reduced using the Image Reduction and Analysis Facility (IRAF) data reduction pipeline. The presence of nuclear non-thermal component in the host galaxy of each source was confirmed by measuring the K4000 in the rest frame. For each spectrum, the contrast was calculated using the relation:

$$K4000 = \frac{f^+ - f^-}{f^+}, \tag{2.1}$$

where f^- and f^+ are average fluxes within $3750\,\text{Å}$ –$3950\,\text{Å}$ and $4050\,\text{Å}$–$4250\,\text{Å}$, respectively, in rest frame (Caccianiga *et al.* 1999; Landt *et al.* 2002). The fluxes measured in each spectrum are shown in Table 2.

3. The spectra of 3EG J1800-0146 and 3EG J1709-0817

Figure 1 (left panel) represents the optical spectrum of 3EG J1800-0146. The spectrum features some absorption lines at redshift $z = 0.165$, e.g., Ca II H & K $\lambda\lambda 3969\,\text{Å}$, $3934\,\text{Å}$, Mg I b $\lambda\lambda 5169, 5175, 5184\,\text{Å}$ and Na D $\lambda\lambda\, 5890, 5896\,\text{Å}$ in the rest frame. $H_2 0$ absorption $(7168 - 7394\,\text{Å})$ from the Earth's atmosphere, not redshifted has been detected in this source. The line centre, continuum, flux and the equivalent width (W_λ) shown in Table 1 were measured using SPLOT command in IRAF.

It shows a shallow depression ($K4000 = 0.35 \pm 0.02$), suggesting the presence of a strong non-thermal emission in this source, emanating from a jet oriented at a small angle. The spectrum of this source resembles that of a BL Lac (Marcha *et al.* 1996; Landt *et al.* 2002). On the other hand, Figure 1 (right panel) shows the spectrum of 3EG J1709-0817. It features some absorption lines at redshift $z = 0.26$, e.g., Ca II H & K $\lambda\lambda 3969\,\text{Å}$, $3934\,\text{Å}$ and Fe d at $\lambda 4668\,\text{Å}$ in the rest frame (Table 1). The telluric absorption lines resulting from Earth's atmosphere, not redshifted have been identified in this object, e.g., H_2O $(7168 - 7394\,\text{Å})$, and B-Band $(6867 - 6884\,\text{Å})$. The spectrum displays a shallow

Table 1. Absorption lines in 3EG J1800-0146 and 3EG J1709-0817. Each line is redshifted by z = 0.165 and 0.26, respectively.

Absorption line	Line centre (Å)	Continuum (erg s^{-1}cm^{-2}Å^{-1})	Flux (erg s^{-1}cm^{-2}Å^{-1})	W_λ (Å)
		3EG J1800-0146		
Ca II K	4580.18	2.55×10^{-16}	4.95×10^{-16}	1.93
Ca II H	4625.53	2.30×10^{-16}	8.00×10^{-17}	0.34
Mg I b	6046.36	1.25×10^{-15}	8.25×10^{-16}	0.65
Na D	6863.19	1.81×10^{-15}	3.25×10^{-15}	1.79
		3EG J1709-0817		
Ca II K	4973.92	3.483×10^{-16}	6.95×10^{-16}	1.996
Ca II H	4997.05	3.472×10^{-16}	6.69×10^{-16}	1.927
Fe d	5882.79	8.13×10^{-16}	2.03×10^{-15}	2.49

Table 2. Ca depression near 4000 Å in 3EG J1800-0146 and 3EG J1709-0817 spectra.

Object	Ca band (Å, rest frame)	Ca band (Å, redshifted)	z	Flux (erg s^{-1}cm^{-2}Å^{-1})	K4000	Class by K4000
3EG J1800-0146	3750 − 3950	4368.75 − 4601.75	0.165	f$^-$ = (2.170 ± 0.040)×10^{-16}		
	4050 − 4250	4718.25 − 4951.25		f$^+$ = (3.322 ± 0.035)×10^{-16}	0.346±0.02	BL Lac
3EG J1709-0817	3750 − 3950	4725 − 4977	0.26	f$^-$ = (4.333 ± 0.030)×10^{-16}		
	4050 − 4250	5103 − 5355		f$^+$ = (5.720 ± 0.050)×10^{-16}	0.242±0.01	BL Lac

depression, K4000 = 0.24 ± 0.01. This is within the range of 0.25 ≤ K4000 ≤ 0.4 of typical BL Lac candidates (Marcha *et al.* 1996). In Table 2, we present the average fluxes, f$^-$ and f$^+$ used for the measurement of K4000 in the two spectra.

4. Conclusions

From our spectroscopic data, we confirmed 3EG J1800-0146 and 3EG J1709-0817 as extragalactic objects with redshift z = 0.165 and 0.26, respectively, and as BL Lacs through the strength of their K4000 contrast.

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