104-cm Sampurnanand Telescope Golden Jubilee Workshop, Oct 17-19, 2022
``Role of meter class telescopes in modern day astronomy"

Optical variability of TeV blazars using 104-cm telescope facility

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Abstract

We present the results of optical photometric observations of five TeV blazars taken with 1.04 m Sampurnanand Telescope in ARIES, India during 2016–2018. We examined the intraday light curves of these blazars for flux variations using the power-enhanced F-test and the nested ANOVA test. We found that the sources are either non-variable or show less amplitude of variations on intraday timescales. On yearly time-scales, all three blazars showed clear flux variations in all optical wavebands. We estimated the weighted mean optical spectral indices of these blazars by fitting a single power law ($F_\nu \propto \nu^{-\alpha}$) in their optical (VRI) spectral energy distributions. We also detected a bluer-when-brighter trend only in the blazar 1ES 0414+009.

Introduction

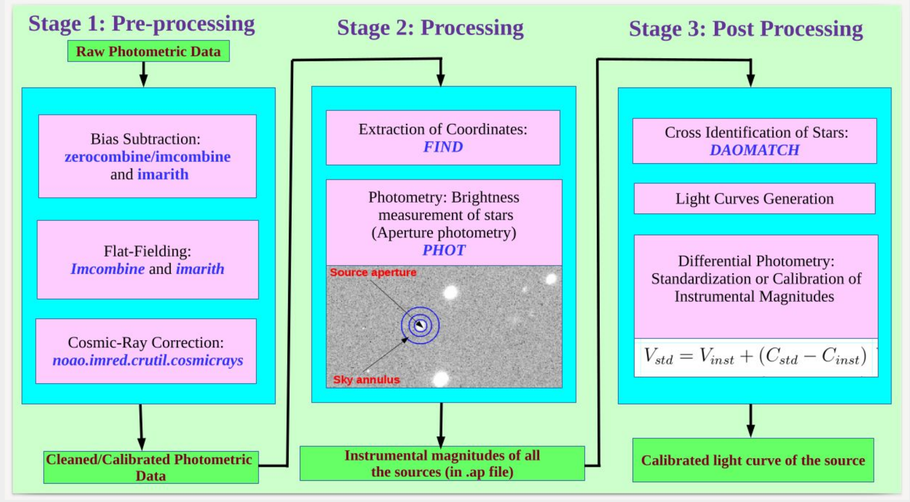
- Blazars are the active galactic nuclei (AGNs) with relativistic jets aligned at an angle of <=10° from the observer's line of sight.
- Blazars, that are significantly detected at TeV energies, are known as TeV blazars.
- To date, about 76 TeV blazars have been detected, most (~55) of which are HBLs.
- Blazars are known for their highly variable nature on diverse timescales over entire electromagnetic spectrum.
- Flux variability observed on intraday (IDV; less than a day) timescale is a puzzling issue that implies a compact emitting region close to the central supermassive black hole.
- The study of IDV provides an opportunity to understand the physics and geometry of these otherwise inaccessible inner regions.

Observations and Data reduction

- The optical photometric observations of five TeV HBLs, listed in Table 1, were carried out in Johnson BV and Cousins RI filters between 2016 April 6 and 2018 December 29 using 104-cm ST.

Table 1. RA, Dec, and redshift of the observed TeV blazars.

Blazar Name	RA (α_{2000})	Dec (δ_{2000})	Redshift (z)
1ES 0229+200	$02^h32^m53^s$	$+20°16'21''$	0.140
1ES 0414+009	$04^h16^m53^s$	$+01°05'20''$	0.287
1ES 0806+524	$08^h09^m49^s$	$+52°18'58''$	0.138
1ES 1553+113	$15^h55^m43^s$	$+11°11'24''$	0.500
1ES 2344+514	$23^h47^m04^s$	$+51°42'18''$	0.044



Stages of the optical photometric data analysis.

Analysis Techniques

1. Power-enhanced F-test

- It compares the variance of the differential light curve (DLC) of blazar to the combined variance of the DLCs of multiple comparison stars.
- The power-enhanced F-statistic is defined as

$$F_{\rm enh} = \frac{s^2_{\rm blz}}{s^2_c},$$

where, s^2_{blz} is the variance of the DLC of blazar and s^2_c is the combined variance of the DLCs of several comparison stars.

$$s^2_c = \frac{1}{\left(\sum_{j=1}^{k} N_j\right) - k} \sum_{j=1}^{k} \sum_{i=1}^{N_i} s^2_{j,i}, \qquad s^2_{j,i} = \omega_j (m_{j,i} - \bar{m}_j)^2,$$

where ω_j is a scaling factor (ratio of the averaged square error of the blazar DLC to the averaged squared error of the comparison star DLC.

2. Nested ANOVA

- It compares the means of dispersion between the groups of observations.
- The F-statistic is defined as

$$F = \frac{MS_{Group}}{MS_{O(G)}}$$

where MS_{Group} and $MS_{O(G)}$ are the mean square due to groups and the mean square due to nested observations in groups, respectively.

Note: A light curve is declared as variable (V) only if significant variations were detected by both the tests, otherwise we conservatively label it non-variable (NV).

3. Intraday Variability Amplitude

$$\text{Amp} = 100 \times \sqrt{(A_{\max} - A_{\min})^2 - 2\sigma^2},$$

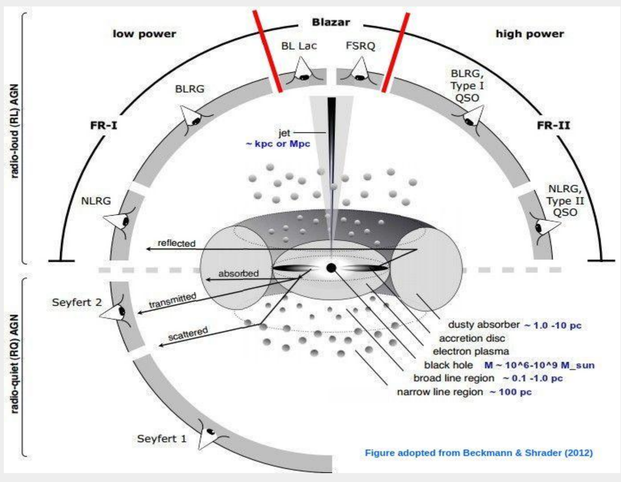


Fig 1) Schematic representation of the basic AGN components.

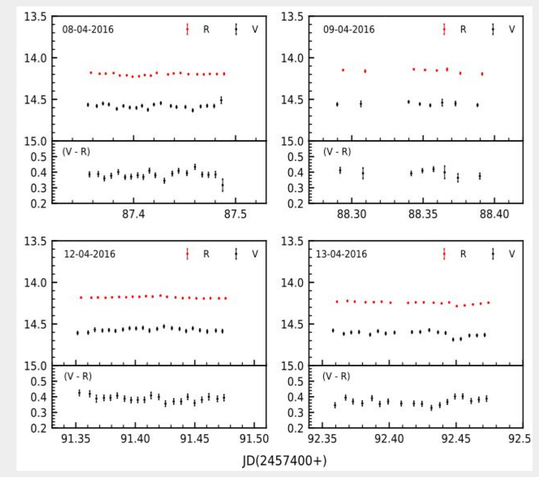


Fig 2) Sample light curves of PG 1553+113

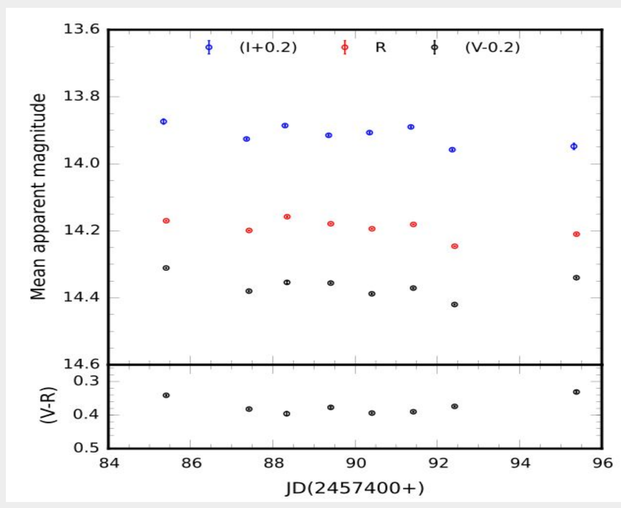


Fig 3) STV of PG 1553+113.

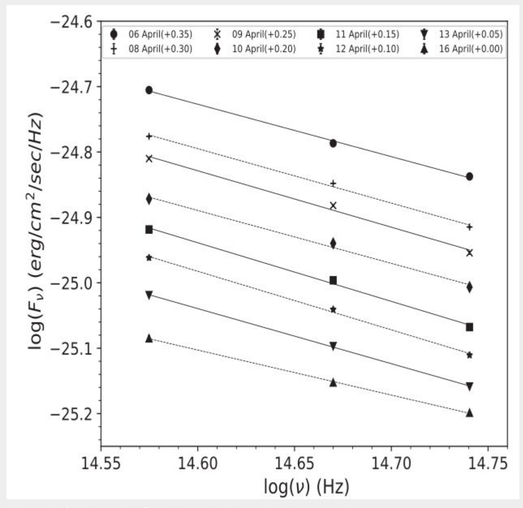


Fig 4) SED of PG 1553+113 in V, R, and I band.

Table 2. Results of IDV analysis.

Blazar Name	Observation date	Band	*Power-enhanced F-test*			*Nested ANOVA*			Status	Amplitude
	dd-mm-yyyy		DoF(ν_1,ν_2)	F_{enh}	F_c	DoF(ν_1,ν_2)	F	F_c		%
PG 1553+113	06-04-2016	V	27, 54	1.33	2.11	6, 21	7.14	3.81	NV	-
		R	27, 54	1.34	2.11	6, 21	10.27	3.81	NV	-
		V-R	27, 54	1.11	2.11	6, 21	1.99	3.81	NV	-
	08-04-2016	V	19, 38	2.07	2.42	4, 15	1.17	4.89	NV	-
		R	19, 38	4.32	2.42	4, 15	15.02	4.89	V	4.76
		V-R	19, 38	1.46	2.42	4, 15	1.60	4.89	NV	-
	09-04-2016	V	7, 14	0.24	4.28	1, 6	3.23	13.75	NV	-
		R	7, 14	7.17	4.28	1, 6	1.11	13.75	NV	-
		V-R	7, 14	0.44	4.28	1, 6	7.58	13.75	NV	-
	10-04-2016	V	15, 30	1.05	2.70	3, 12	1.34	5.95	NV	-
		R	15, 30	1.09	2.70	3, 12	0.43	5.95	NV	-
		V-R	15, 30	1.36	2.70	3, 12	1.42	5.95	NV	-
	11-04-2016	V	19, 38	0.84	2.42	4, 15	2.67	4.89	NV	-
		R	19, 38	2.09	2.42	4, 15	2.40	4.89	NV	-
		V-R	19, 38	1.05	2.42	4, 15	2.64	4.89	NV	-
	12-04-2016	V	20, 40	0.85	2.37	4, 15	7.22	4.89	NV	-
		R	20, 40	4.31	2.37	4, 15	14.53	4.89	V	3.44
		V-R	20, 40	0.70	2.37	4, 15	6.34	4.89	NV	-
	13-04-2016	V	17, 34	3.57	2.54	3, 12	7.25	5.95	V	11.23
		R	17, 34	7.45	2.54	3, 12	6.55	5.95	V	6.17
		V-R	17, 34	1.70	2.54	3, 12	5.32	5.95	NV	-
	16-04-2016	V	18, 36	0.29	2.48	3, 12	0.73	5.95	NV	-
		R	18, 36	0.22	2.48	3, 12	0.58	5.95	NV	-
		V-R	18, 36	0.10	2.48	3, 12	0.28	5.95	NV	-
1ES 2344+514	25-10-2016	R	58, 58	1.60	1.86	10, 44	19.55	2.75	NV	-
	26-10-2016	R	69, 69	0.74	1.76	13, 56	3.41	2.47	NV	-
	08-11-2016	R	40, 40	0.15	2.11	7, 32	7.10	3.26	NV	-
	09-11-2016	R	33, 33	0.50	2.29	5, 24	1.39	3.90	NV	-
	24-11-2016	R	69, 69	1.53	1.76	13, 56	8.49	2.47	NV	-
	25-11-2016	R	59, 59	1.35	1.85	11, 48	13.47	2.64	NV	-
	29-12-2016	R	35, 35	1.84	2.23	6, 28	8.02	3.53	NV	-
	10-10-2018	R	94, 94	2.12	1.62	18, 76	8.86	2.18	V	2.26
	15-10-2018	R	69, 69	1.33	1.76	13, 56	1.82	2.47	NV	-
	15-12-2018	R	59, 59	1.68	1.85	11, 48	7.68	2.64	NV	-
	16-12-2018	R	59, 59	1.25	1.85	11, 48	5.43	2.64	NV	-

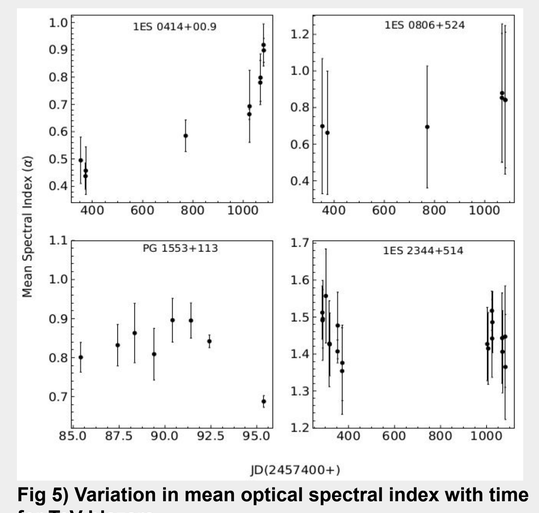


Fig 5) Variation in mean optical spectral index with time for TeV blazars.

Results

- Significant intraday flux variations were detected in both V and R band LCs only on 2018 January 10 for 1ES 0806+524 and on 2016 April 13 for 1ES 1553+113. In addition, we found significant IDV only in R band LCs of 1ES 1553+113 on 2016 April 8, and 12, while no IDV was detected in V band LCs on those nights.
- No significant IDV was observed on any night for TeV HBLs 1ES 0229+200, 1ES 0414+009, and 1ES 2344+514.
- We found no temporal V − R color variation on IDV timescale for these TeV blazars.
- We also did not find any variation in V − R color with R band magnitude on IDV timescale.
- We found flux and color variations on STV/LTV timescales in all five TeV blazars.
- We estimated a mean optical spectral index of 0.67±0.01, 0.639±0.002, 0.83±0.02, and 1.37±0.01 for TeV blazars 1ES 0414+009, 1ES 0806+524, PG 1553+113, and 1ES 2344+514, respectively.

Discussion and Conclusion

- At optical wavelengths, TeV blazars are less variable and their variability amplitudes are very small that can be explained by the turbulence in the relativistic plasma.
- On STV/LTV timescales, TeV blazars show flux and color variations that can reasonably be explained by the shock-in-jet models.
- We did not find the bluer-when-brighter trend for our TeV blazars. But we still need more optical observations of other TeV blazars to come to any conclusion.
- The optical variability amplitude usually decreases with increasing brightness for the TeV blazars. But again we need more observations of TeV blazars to conclude any result.

Further details about this work can be found in the following papers.

- Pandey et al, 2019, ApJ, 871, 192
- Pandey et al, 2020, ApJ, 890, 72
- Pandey et al, 2020, MNRAS, 496, 1430

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Thank you for your time !