Measuring the Microvariability of BL Lac

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Abstract:

During the night of October 23, 2004, observations were taken by Tri Nguyen at Kitt Peak National Observatory to measure the microvariability of the Active Galactic Nucleus, BL Lac, the first blazer ever found. Using the images observed from the night of October 23, 2004, v-magnitude data was extracted and used to construct a light curve of this object. From this graph, greatest changes in variation of approximately 0.0393 magnitude occurred over several minutes. This shows that it is not significant compared to the measured error. This confirms that BL Lac had little changes in magnitude showing no significant variations on a time scale of minutes.

Introduction:

Active Galactic Nuclei (AGN) are galaxies that transmits high amounts of energy from their core and are believed that the galaxies core are black holes. These galaxies are surrounded by an accretion disk that is composed of debris, high-energy particles, and radiation. The black hole emits high levels of photons that are gamma rays and there are correlations between masses of these black holes and velocity dispersions in active galaxies. (Kotilainen, J., Falomo, R. & Treves, A. 2003) Around the accretion disk is a cloud shaped object of matter that blocks off some of the gamma rays called the torus. There is evidence that there are jets that shoot out gamma ray radiation. There are two beams of these jets each in opposite directions of the black hole. The interaction of these jets with galaxies has a relationship in the role for acceleration of high-energy particles in Active Galactic Nuclei (Pohl, M. 2003)

Because these Active Galaxies vary on different time scales, there are different phenomena at the core of active galaxies that can cause measurable variability on a time scale of minutes and hours. Over the past several years, there has been evidence variability for many types of Active Galactic Nuclei. (Miller, H. et al. 1999, Massaro, E., et al. 1999, Nesci, R. et al. 1999, Millar, H.R. et al. 1999, Tosti , G. et al. 1999, De Diego, J.A. et al. 1997) The purpose of this paper is to detect luminosity changes and provide data of the microvariability of the Active Galactic Nuclei, BL Lac.

Observations and Reduction:

Observations were taken using the Wisconsin Indiana Yale NOAO (WIYN) 0.9 meter telescope at Kitt Peak near Tucson, Arizona and the CCD camera used was S2KB (2048 x 2048 Silicon Imaging CCD Camera). The Unix computer called “Olive” controlled the telescope and the computer called “Taupe” controlled the camera. The computer, running the UNIX operating system, uses a program called IRAF (Image Reduction and Analysis Facility), which is used on “Taupe” to perform the data reduction and data acquisitions. (Tody 1993) Data reduction is needed to reduce the raw image by subtracting all sources of noise and electron buildup given from the electronics. This is needed in order to get the highest quality image of the object being observed. There are three types of errors involved and can be corrected using Bias Frames, the readout differences for each pixel, Flat Frames, the optical imperfections in the telescope and camera, and Dark Frames, the electronic chip noise and temperature. Bias and Flat Frames were only needed for the data reduction. Dark Frame is not needed with this particular camera/telescope because the camera is chilled with liquid nitrogen.

On October 23, 2004, during the afternoon, preparations were made before observing by taking these types of frames. The bias frames were made using a 0 second exposure time. Approximately 10 exposures were made. Flat frames were made with each type of filter. Before they were taken, the Dewar was filled with liquid nitrogen to keep the electronics cool and was refilled every 8 hours. In the control room, the telescope was slewed to the mirror cover park position so that the cover could be taken off. After taken off, the telescope was slewed to the dome flat park position which points to a white flat circle in the dome. Five Flat Frames were made for each type of filter. The filters were B, V, R, and H-alpha. Each filter has its own Dome Flat Exposure Settings. For these four filters, the Lamp Setting is at low luminosity at 100%. The exposure times for these filters were: B–13sec, V– 5sec, R– 3s, H-alpha- 60sec.

After the bias and flat frames were taken, to begin observing, the dome shutter was opened and dome fans were turned on. Also, the dome vents were opened and dome lights were turned off. In the control room, we slewed the telescope to zenith. Then we moved the telescope to a bright star near the zenith and turn on telescope tracking and auto dome. To begin observing, we went to the first object and checked to make sure the telescope was in focus. Images were taken beginning at 6 PM.

At around 9PM, we started taking images of BL Lac using a V filter. Using the exposure time calculator from the NOAO website, we used an exposure time of 4 seconds for a 100 signal-to-noise ratio (SNR) at the given magnitude of 14.5 from the GTN Program Catalog. (Computing Exposure Times with the IRAF Task CCDTIME 2004) Unfortunately the brightness counts only showed up around 400 brightness counts (BC, pixel value). We raised the exposure times to 30 seconds and the BC were around 3500. Again, we raised the exposure to 60 seconds to get brightness counts of around 6000. This exposure time seemed to be the best maximum SNR without over exposing the image. With the signal to noise improved, we stayed on this object taking images until around 10:35PM. To make sure the objects were still in focus, we checked the various stars around the image using IRAF’s profile tool which graphs the pixel value (y-axis) and the Radius (x-axis).

Image Calibrations were made using IRAF after all observations were taken. The bias and flat frames were averaged and then subtracted from the raw image. Katy Garmany did these image calibrations.

Determining Magnitudes:

Using the calibrated images, the program, HOU Image Processing, was used to extract brightness counts off each image by using finder charts for the AGN and the standard stars given in the Global Telescope Network (GTN) program catalog.

Figure 1. Finder chart of BL Lac from GTN Program Catalog (Spear 2004). The letters represent names for the standard stars and BL Lac is located with the bracket lines.

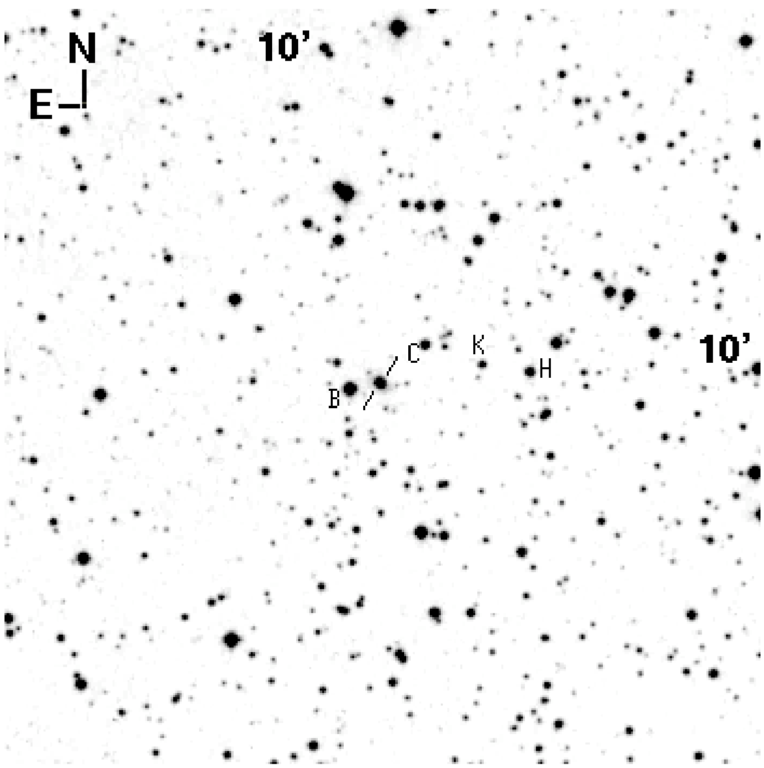
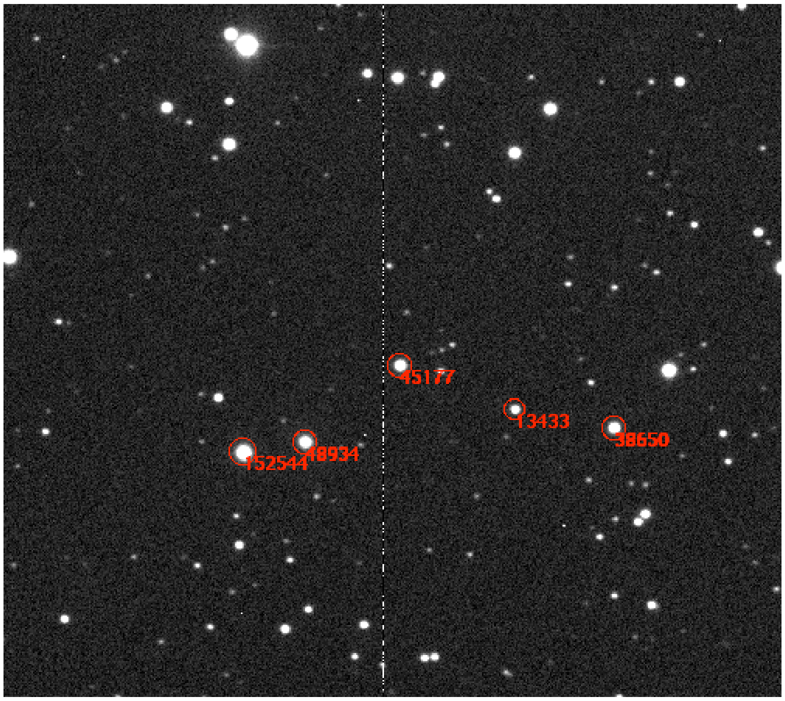


Table 1. List of standard star magnitudes for BL Lac for V filters from GTN Program Catalog (Spear 2004).

Star	V	V Uncert.
B	12.78	0.04
C	14.19	0.03
H	14.31	0.05
K	15.44	0.03

Figure 2. This is a sample images taken on October 23, 2004 at Kitt Peak National Observatory using the 0.9 meter WIYN telescope. (Image 10) The red circles are the apertures that are directed around the standard stars and BL Lac.



An aperture was directed around each object, the AGN and Standard stars, to obtain their brightness counts. The size of the aperture was set at the default, an auto-aperture, making then aperture size adjust to the size of the star. In certain images, there was a bad row, which overlapped the standard star C, because of this problem, star C was omitted to correct the problem during the magnitude calculation, but only for those images that were overlapped. In figure 2, the bad row appears, but does not overlap standard star C.

The statistical analysis program, Fathom, was used to compute magnitudes. (Fathom c 2004) The data of brightness counts was input into a table including the magnitude of the standard stars given in the Global Telescope Network (GTN) catalog.

Table 2. Example of Magnitude and Brightness Counts of Standard Stars taken from Image 11

Collection 1

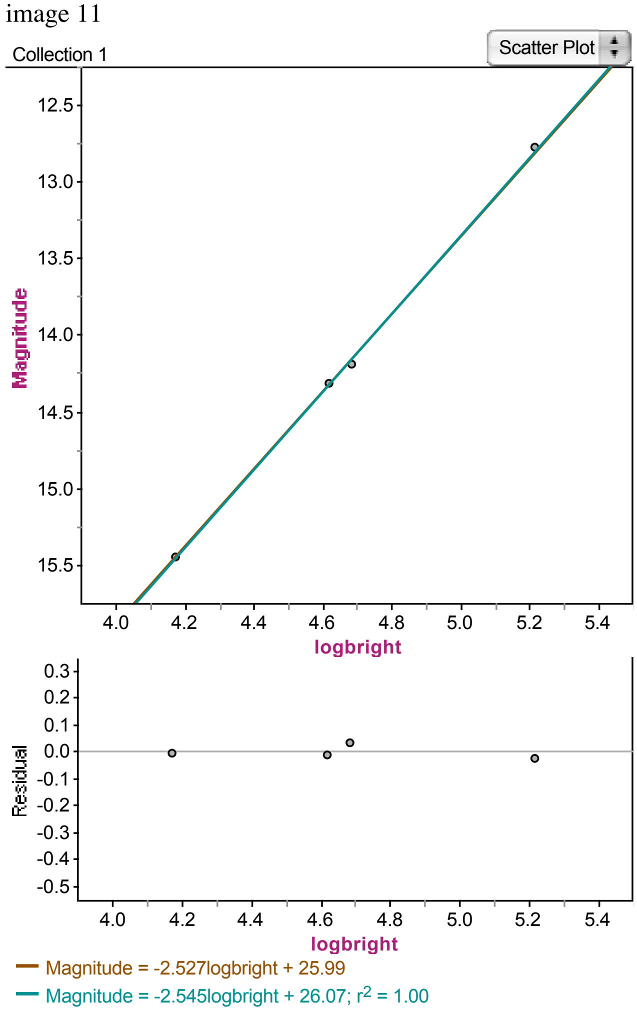
	star	Magnitu…	Brightn…	logbright
=				log (Brightnes
1	Star B	12.780	164483	5.21612
2	Star H	14.310	41418	4.61719
3	Star K	15.440	14825	4.17099
4	Star C	14.190	48201	4.68306

Once computed, the data was plotted on a graph using this magnitude equation:

Equation 1:

$$M_1 = M_2 + 2.5 \log (B_2/B_1)$$

Figure 3. Example of Graph of Standard Star magnitudes vs. Measured Log of Brightness Counts from image 11



Using the Fathom program, a statistical analysis was made by making a simple regression model. It was calculated from the data set using the log of the brightness counts from the standard stars and BL Lac and the standard stars magnitudes to get the magnitude and error of the AGN, BL Lac. In order to build a simple regression model, the response attribute, Magnitude, and a predictor attribute, logbright, had to be selected by dragging the Magnitude and logbright from the graph to the model window. Once the simple regression was formed, it gave a computed magnitude of BL Lac with error.

Figure 4. Example of Simple Regression of Magnitude and the log of brightness from image 11

BL Lac BC = 53286
Log of BL Lac = 4.72661

Model of Collection 1 Simple Regression

Response attribute (numeric): Magnitude
Predictor attribute (numeric): logbright

Sample count: **4**

Equation of least-squares regression line:
Magnitude = **-2.54462 logbright + 26.068**
Correlation coefficient, r = **-0.999719**
r-squared = **0.99944**, indicating that **99.944**% of the variation in **Magnitude** is accounted for by **logbright**.

The best estimate for the slope is **-2.54462** +/- **0.183525** at a **95** % confidence level. (The standard error of the slope is **0.042654**.)

When **logbright** = **4.72661** , the predicted value for a future observation of **Magnitude** is **14.0406** +/- **0.152531**.

The Universal Time from each image was converted to a Julian Date using a Julian Date converter. (Julian Date Converter 2004) Then all magnitude, error, and Julian Dates from the BL Lac Images were put into a table to construct a light curve. After all data was collected, a light curve for the object, BL Lac was made.

Table 3. The table below represents the slopes and y-intercepts from the line of best fit used to calculate magnitude for each individual image.

Image Number	Slope of Standard Star Fit	Intercept
1	-2.53106	26.05
2	-2.51503	25.892
3	-2.53133	25.994
4	-2.53123	25.948
5	-2.54173	26.06
6	-2.53938	26.059
7	-2.5449	26.054
8	-2.52314	25.927
9	-2.50866	25.962
10	-2.50918	25.822
11	-2.54462	26.068
12	-2.53688	26.018
13	-2.56133	26.156
14	-2.54243	26.037
15	-2.5385	26.015
16	-2.53558	26.029

17	-2.54834	26.091
18	-2.54124	25.688
19	-2.49922	25.388
20	-2.54339	25.892
21	-2.52084	25.973
22	-2.57016	26.226
23	-2.51572	25.942

Table 4. All computed magnitudes, Julian Dates, errors, and exposure times for BL Lac

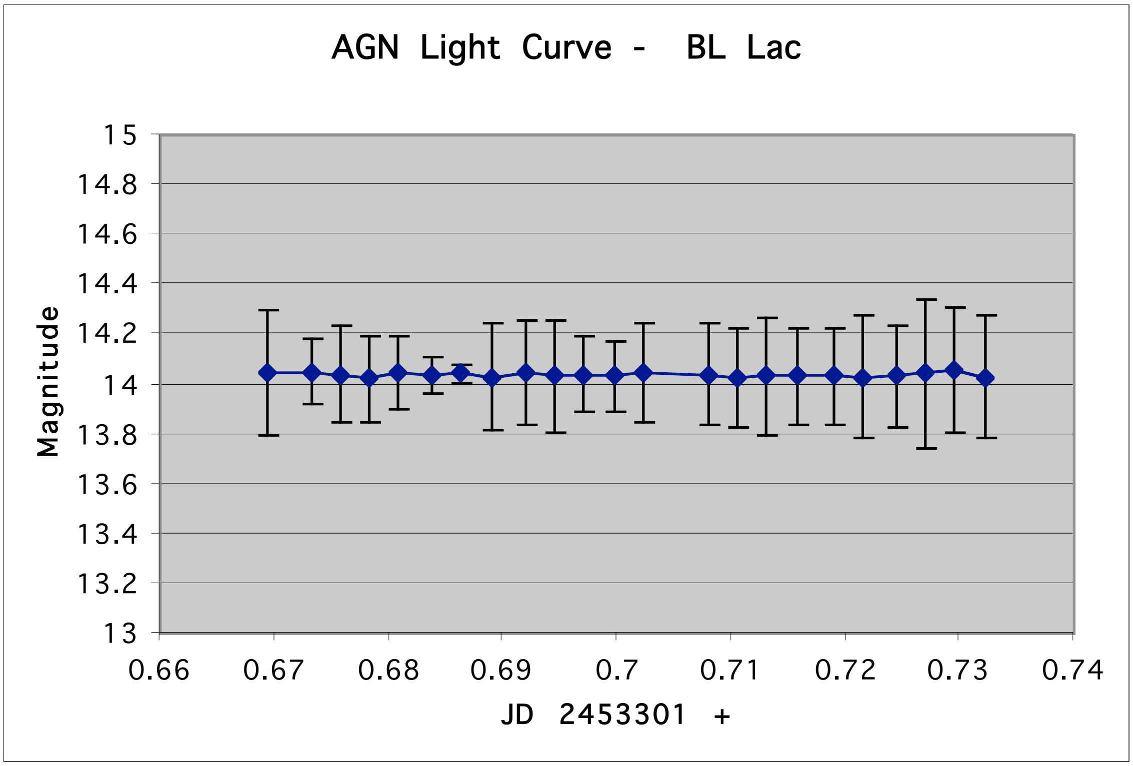
Image Number	Magnitude	Error	Min	Max	JD2453301+	Exposure Times (seconds)
1	14.0472	0.246574	13.8006	14.2938	0.66926	60
2	14.0503	0.133099	13.9172	14.1834	0.67324	60
3	14.0406	0.197264	13.8433	14.2379	0.67579	60
4	14.0215	0.173008	13.8485	14.1945	0.67834	60
5	14.0469	0.149492	13.8974	14.1964	0.68089	60
6	14.0357	0.072895	13.9628	14.1086	0.68384	60
7	14.0419	0.032092	14.0098	14.0740	0.68639	60
8	14.0298	0.214515	13.8153	14.2443	0.68895	60
9	14.0447	0.208711	13.8360	14.2534	0.69203	60
10	14.0339	0.225694	13.8082	14.2596	0.69457	60
11	14.0406	0.152531	13.8881	14.1931	0.69714	60
12	14.0332	0.142634	13.8906	14.1758	0.69970	60
13	14.0469	0.195689	13.8512	14.2426	0.70225	60
14	14.0418	0.202050	13.8398	14.2439	0.70802	60
15	14.0247	0.201665	13.8230	14.2264	0.71057	60
16	14.0315	0.236416	13.7951	14.2679	0.71312	60
17	14.0332	0.193948	13.8393	14.2271	0.71568	60
18	14.0319	0.192319	13.8396	14.2242	0.71896	60
19	14.0282	0.246285	13.7819	14.2745	0.72150	60
20	14.0334	0.206301	13.8271	14.2397	0.72448	60
21	14.0440	0.297113	13.7469	14.3411	0.72703	60
22	14.0608	0.253065	13.8077	14.3139	0.72958	60
23	14.0308	0.244513	13.7863	14.2753	0.73214	60

This object was monitored only for one night due to cloudiness, humidity, and turbulence, but with the data collected, it showed very little direction toward microvariability. The results of the variation detected are displayed in figure 5 and table 4. Greatest changes in variation of approximately 0.0393 mag occurred over several minutes. This is not significant compared to the measurement error.

Conclusions:

The observations revealed that there were no large variations in brightness on timescales of minutes that were observed for the Active Galactic Nuclei, BL Lac on the night of October 23, 2004. Though there were no variations found in this night, BL Lac has had variations detected from it before. Microvariability of active galaxies are uncommon, but can be seen. There has been no pattern of microvariability occurrences. Variations from active galaxies are often wild making them unpredictable and rare to be seen, but searching for these types of variations when found can help find out more information on active galaxies because there is little information in this area. Although there were no significant variations found on this night, continued research will be conducted to find these types of variations. If these variations are found, it can be used to find the size of the event horizon of the black hole in light-minutes or light-hours.

Figure 5. The light curve for BL Lac obtained on October 23, 2004.



Acknowledgements:

Special thanks to Teacher Leaders in Research Based Science Education (TLRBSE), Kitt Peak National Observatory (KPNO), National Optical Astronomy Observatory (NOAO), Global Telescope Network (GTN), and the Deer Valley High School ESPACE Academy.

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