TEXAS TECH UNIVERSITY
Department *of* Physics & Astronomy

ASTR 2401 Observational Astronomy
Fall 2023 - Dr. Vallia Antoniou

OBSERVING PROPOSAL FOR TIME
AT THE PRESTON GOTT SKYVIEW OBSERVATORY

Name: Elliott Walker
Observing Partner: Elizabeth Veraa
Total exposure time / number of nights requested: 12-16 hours / 3-4 nights

Proposal for Short-Term Observation of Intra- and Inter-night Variability of BL Lacertae

1 Abstract

BL Lacertae (BL Lac) is the prototype object of a class of active galactic nuclei of the same name. It is known to exhibit highly variable behavior in both optical and radio wavelengths, thought to be the result of relativistic beaming from a supermassive black hole's outflow jet. We seek observing time in order to better understand the variability of this object across short time periods of a few hours (intra-night) to a few days (inter-night). Along with overall variations in magnitude, changes in color have also been observed over time, and so we hope to make photometric observations in multiple optical filters in order to measure this effect. By making various observations within each night across multiple nights, we will hopefully be able to determine to some extent the intensity and consistency of BL Lac's variability. Our data processing will likely consist of creating an automated system to handle part or all of the analysis.

Keywords: BL Lacertae objects: individual (BL Lacertae) — galaxies: jets — galaxies: photometry — methods: data analysis

2 Summary of observing runs requested and scheduling constraints

Run	Telescope	Instrument	Filters	Hours	Continuous
1	12-inch	STC-428-P	*g'*,*r'*,*i'*	4	no
2	12-inch	STC-428-P	*g'*,*r'*,*i'*	4	no
3	12-inch	STC-428-P	*g'*,*r'*,*i'*	4	no
4 (optional)	12-inch	STC-428-P	*g'*,*r'*,*i'*	4	no

We request 4hr observations on three to four different nights, totaling 12-16hr. Of this, 3hr per night is to be spent actively taking science images, while the remaining time is allocated for overhead. Three nights will be sufficient to conduct our analysis, but if possible a fourth night would allow for a more robust investigation. Ideally the nights are non-consecutive with spacing of multiple (2-5) days, in order to allow for a greater time period over which to estimate inter-night variability.

3 Scientific Justification

In 2021, extreme flaring behavior was observed, with the object's peak magnitude in the R-band reaching approximately 11 (Nozaki et al., 2023). During this time, time-delay between peaks in the different bands was observed (Bachev et al., 2023), something present in the typical variability of BL Lac but more extreme during this time.

Variability has generally been observed for BL Lac on multiple time-scales. Generally, these are classified into variability over a few hours (the course of a night, referred to as "intra-night") and over longer periods of a few days to weeks (the course of multiple observing nights, referred to as "inter-night") These different periods of variability, especially the micro-variability on the intra-night scale, have been used to model the likely dynamics of the object's jet (Xu et al., 2023).

In Figure 1, we include light curves for four different Sloan filters (V, R, B, I) presented in Bachev et al., 2023, each one an "intra-night" curve for one of two different nights during the 2021 peak flaring state. The irregularity of BL Lac's variability is apparent from this figure. Slight offset can be noticed between the changes of intensity in each band. Because of this, we will also make observations in multiple bands, so that we can potentially see discrepancy in flux changes in different wavelengths.

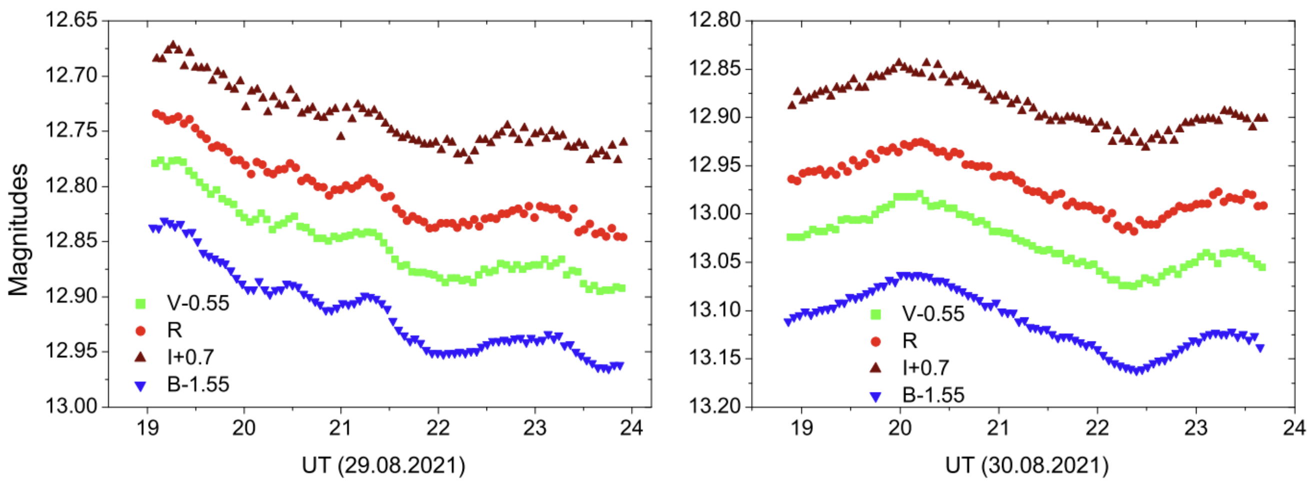


Figure 1: *Light curves from two nights of observation during 2021 peak state (Bachev et al., 2023).*

4 Technical Justification

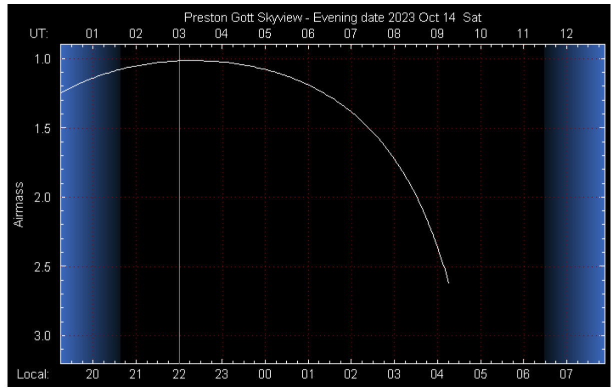
BL Lac is a fairly bright target for an object of its type, with its apparent V-band magnitude having been reported to vary between approximately 14 and 17 (Oke and Gunn, 1974).

Our plan for observation is to alternate between the Sloan g', r', and i' bands, taking 20 minute combined exposures per hour in each filter across three hours of lights observation nightly. This will allow us to conduct photometry to generate rough light curves within each night, with three main points of data in each color (potentially more, if our photometry is precise enough to allow for multiple points within each twenty-minute period), allowing for an estimation of the intra-night variability. Our photometry will be absolute, with the goal of comparing against previous results from the literature.

We hope to conduct observation within the month of October 2023, and so in Figure 2 we include hourly circumstances and an airmass graph for the night of 14 October, the date of the month's new moon. We also include a finding chart for the target at the end of this document.

Local	UT	LST	HA	Airmass	moonalt	sunalt
Sat Oct 14 19:00	00:00	18:45	-3:18	1.29	3.0	2.3
Sat Oct 14 20:00	01:00	19:45	-2:18	1.14	---	-10.1
Sat Oct 14 21:00	02:00	20:46	-1:18	1.05	---	---
Sat Oct 14 22:00	03:00	21:46	-0:18	1.01	---	---
Sat Oct 14 23:00	04:00	22:46	+0:42	1.02	---	---
Sun Oct 15 00:00	05:00	23:46	+1:42	1.08	---	---
Sun Oct 15 01:00	06:00	00:46	+2:43	1.19	---	---
Sun Oct 15 02:00	07:00	01:46	+3:43	1.39	---	---
Sun Oct 15 03:00	08:00	02:47	+4:43	1.73	---	---

(a) Hourly circumstances



(b) Airmass plot

Figure 2: *Observing conditions for BL Lac predicted for the night of 14 October 2023*

5 Management Plan

The end goal is a set of absolute photometry data for the target object. A major component of this project will hopefully be conducting the majority of data processing via a fully-automated system based in Python rather than manually with a partially-automated system which utilizes software such as AstroImageJ (AIJ) and Aperture Photometry Tool (APT). The goal is to develop a scripted pipeline which takes the full raw dataset as outputted during the imaging time and uses this to conduct a 6-step process as follows:

1. Calibration/pre-processing
   - Python astropy (Astropy Collaboration et al., 2022) and CCDProc (Craig et al., 2017) packages
   - Data will be sorted, master calibration frames will be created for each night, and science frames will then be properly calibrated (bias+dark subtraction and flat division).
2. Alignment
   - Python astroalign (Beroiz, Cabral, and Sanchez, 2020) package
   - Using a 3-point-asterism matching algorithm, Astroalign will determine and apply the necessary transformations to align calibrated frames to eachother.
3. Stacking
   - Python astropy and CCDProc packages
   - We will stack together frames to generate each image for a single final photometric datapoint: potentially 120 frames (20 minutes) at a time, or fewer to create more datapoints if the data is "clean" enough.
4. Astrometric solution
   - Python astroquery.astrometry_net (Ginsburg et al., 2019) package
   - By querying the astrometry.net API (Lang et al., 2010) we can obtain astrometric solutions for each of our images.
5. Source detection and solution
   - Python astroquery.sdss and photutils (Bradley et al., 2023) packages
   - Once astrometric solutions have been obtained, we will generate a source list with photutils, determine flux and instrumental magnitudes for this list, and then cross-match these sources with a reference catalog (such as SDSS using the query_region method, or possibly something else).

This allows us to compute a zero-point and absolutely calibrate our instrumental magnitudes to obtain final photometric data. We will look more into another package called "phot" for some of this process as well.

6. Data output/visualization

   - Python matplotlib (Hunter, 2007) package
   - Data will be outputted as CSV, TSV, and/or ASCII, and proper plots will be generated with PyPlot to visualize the data.

In the case that we are not able to successfully create a functional program to conduct all of these steps, we will continue from wherever the script leaves off using manual tools such as AIJ and APT.

References

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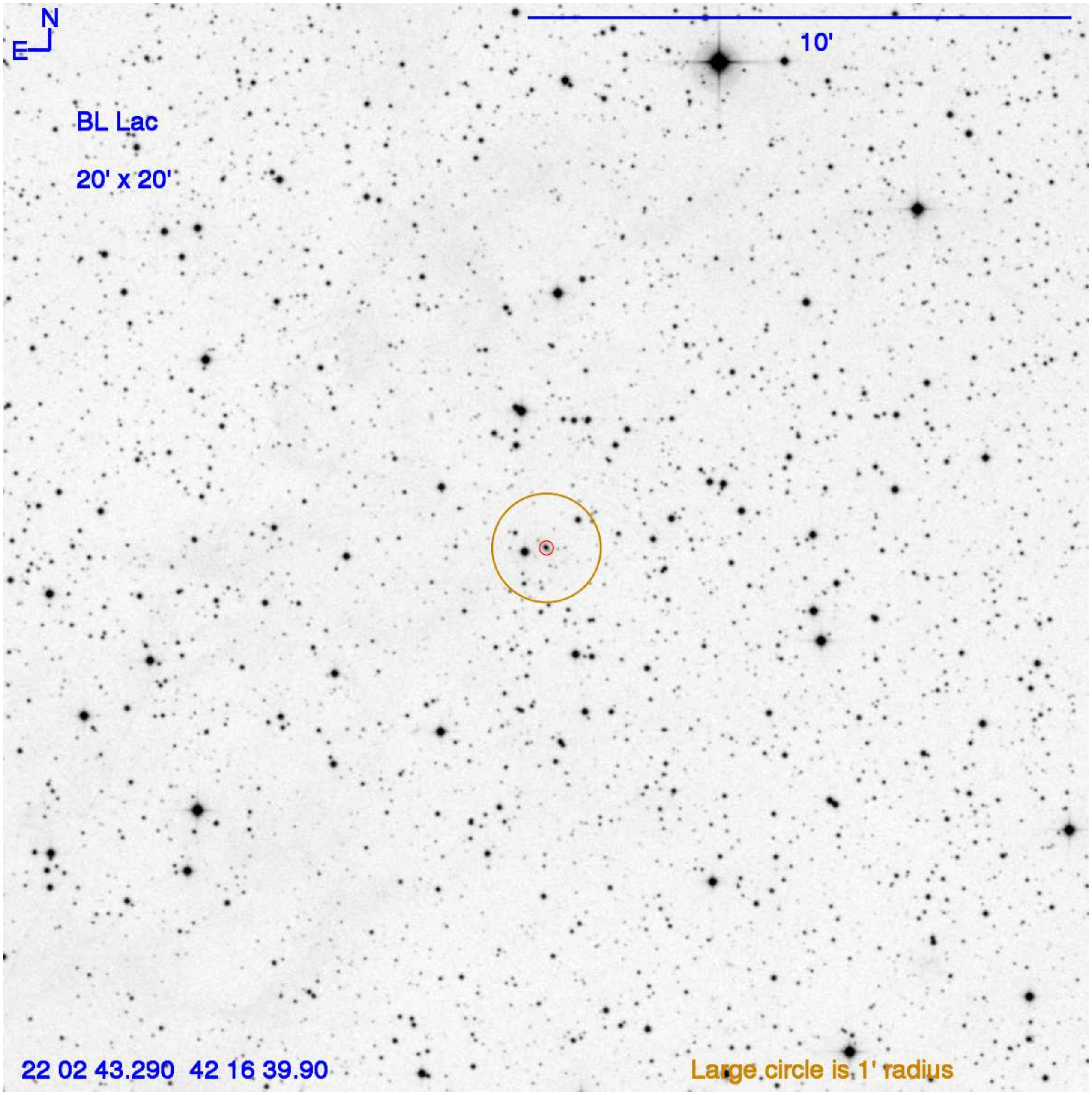

Figure 3: *Finding Chart*