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# Photometric Monitoring of MRK 501: A Model for Measuring the Optical Variability of BL Lacs

Nathan J. McGregor
*Boise State University*

Daryl J. Macomb
*Boise State University*

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## Abstract

Blazars' relativistic jets are oriented close to our line of sight, producing a variation in flux density over time. The physical mechanisms behind these fluctuations are still poorly known. Variability surveys such as ours that combine high photometric accuracy, sufficiently long time baselines, and a high number of observation epochs hold the promise of significant progress. We present photometric observations of Markarian 501 (Mrk 501) imaged in three optical (VRI) bands from 2010 to 2015 using the 0.4m telescope at the Challis Astronomical Observatory (CAO). Astrometric calibration was performed on each image using Astrometry.net. Images that were recognized and calibrated formed the data for our analysis. Artifacts were removed by resampling and co-adding images using SWarp. For each co-added image, we generated an SExtractor catalog and computed an astrometric solution using SCAMP. We used this solution to match Mrk 501 to reference catalogs for modeling light curves. Our first set of light curves presented here form the basis of a long-term photometric variability study of blazars. Future research will produce light curve data for new sources. This data will be cross correlated with catalogs in high energies in order to better understand the source structure and physical processes of blazars.

# PHOTOMETRIC MONITORING OF MRK 501

NATHAN J. MCGREGOR, D. J. MACOMB
Department of Physics

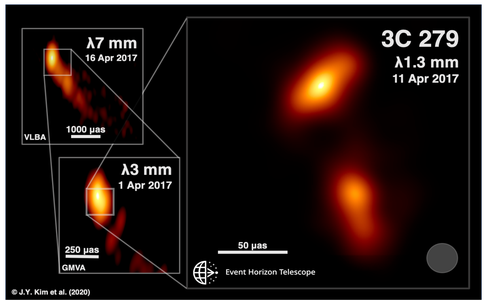
BOISE STATE UNIVERSITY

## A MODEL FOR MEASURING THE OPTICAL VARIABILITY OF BL LACS

## BACKGROUND

### BL Lacertae Objects (BL Lacs)

- $As gas and dust accrete onto the supermassive black holes in galaxies, they give rise to active galactic nuclei (AGN)
- $Some of the most luminous and highly variable of AGNs are BL Lacs, whose relativistic jets are oriented close to our line of sight, producing rapid and large-amplitude flux variability and significant optical polarization




### Data

- $All VRI observations were taken with the automatic 0.40 m telescope at the Challis Astronomical Observatory
- $The telescope is equipped with a CCD camera and UBVRI filters $
- $VRI observations were collected from 2011 through 2015

## METHOD

### Astrometry.net

- $Images that were recognized and astrometrically calibrated formed the data for our analysis.

### SWARP

- $Artifacts were detected and removed by resampling and co-adding 10 FITS images in each band for each observation

### SExtractor

- $A catalog of objects was generated for each co-added image

### Cone Search

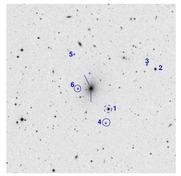
- $Identified Mrk 501 and reference stars by computing great-circle distance (angular on-sky separation) between SExtractor sources and Mrk 501 using Mrk 501's known ICRS RA and Dec

### Plot

- $Because the magnitudes of stars 1 and 4-6 have been measured in all bands in other works, they were selected to calculate Mrk 501's magnitude
- $The average measured magnitude for each band for reference star 1 was used to determine a zero point
- $Mrk 501's flux and magnitude were plotted from 2011 to 2015

R-band Image $

Co-added Image

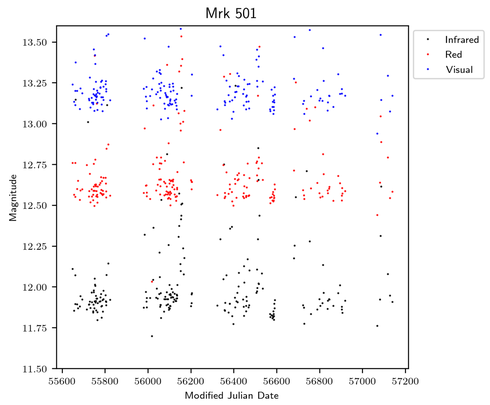


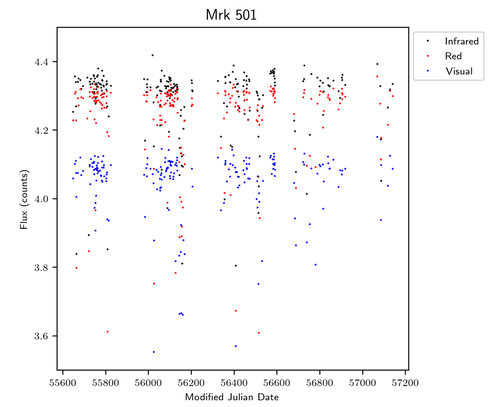
Reference Stars $

## RESULTS

### Mrk 501 and Reference Stars

- $Mrk 501 and the reference stars exhibit little variability in magnitude and flux; however, further calibration is needed in order to better assess Mrk 501's flux variability
- $The measured magnitude for the reference stars are within ±0.2 of their published values




## FUTURE RESEARCH

### Noise

- $Calculate relationship between observation ambient temperature and image noise, so the noise corresponding to the ambient temperature during the observation period could be subtracted
- $Use darks and bias frames to subtract noise

### Error and Statistical Analysis

- $Calculate parameters for data processing (gain for converting counts to flux and zero point for calibrating the magnitude scale)
- $Calculate statistical values and errors

### Correlate with Chandra and Fermi Data

- $ Correlate photometric measurements with x-ray and gamma ray observations during same observation period to assess relationship. X-ray observations provided by the Chandra X-ray Observatory. Gamma ray observations provided by the Fermi Gamma-ray Space Telescope.

### Apply Model to Other BL Lacs

- $ Mrk 421, OJ 287, BL Lacertae, 1ES 1959+650, 3C 66A, S5 0716+71, W Com, RXS J1543+613, OT 081, PKS 0048-097

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