Markarian 421: A Colossus Amongst Giants

Alex Whitman (Mentor: Professor Jamie Kern)

Abstract

Quasars are some of the most amazing objects in the cosmos and yet there is still so much we do not know about them. Markarian 421, is the brightest of these unique objects in our night sky. The main goal of this research is to better understand quasars and how they operate. We observed Markarian 421 using the red, green, infrared, and hydrogen-alpha filters from March 12th, 2021, to July 15th, 2021, in the BSU Observatory dome and constructed light curves for further analysis of the active galactic nucleus (AGN). This project is a first of its kind here at BSU and will pave the way for future students to measure objects of this nature. Understanding AGN such as quasars is vital to comprehending the evolution of galaxies.

Background

Quasars are AGN with a supermassive blackhole in the center, an accretion disk, torus, and relativistic jets that emit an extraordinary amount of energy. These objects existed in great numbers in the distant past, but few exist in our modern universe. Markarian 421, the brightest of these great ancestors, may hold information as to how galaxies evolve, and offer clues toward the fate of the universe. We aimed to collect data to later calculate the size of the quasar's disk using a technique called reverberation mapping. In this technique we image an object and use light curves consisting of many nights to observe a difference in luminosity peaks across different filters. Shorter wavelengths are emitted from the center of the quasar itself, while longer wavelengths are emitted from the gas cloud some light-days away, this delay in filter magnitude peaks is what will allow us to calculate the size of the disk. The speed of the gas in the disk will be determined using the spectrograph, giving us the mass of the central supermassive black hole.

Method

The Bridgewater Experimental Astrophysics Research (BEAR) Team and I took images of Markarian 421 through the green (V), red (R), infrared (I), and hydrogen-alpha (Ha) filters using the Bridgewater State University (BSU) Observatory main telescope. The BSU Observatory main telescope is equipped with a Celestron Edge HD 14" telescope, Paramount ME mount, SBIG-STXL-6303 camera with AO-X adaptive optics plate and an 8-position filter wheel with 50mm round Astrodon V, R, and I filters and Chroma Ha filter. V,R, and I images had exposure times of 40 seconds and 320 seconds in Ha. Data were collected over a five-month span and converted into light curves. Peaks are caused by bursts from the quasar, and shifts are due to where in the AGN they come from. This time-delay between filters gives us the size of the accretion disk, assuming the delay is due to the time it takes for light from the center of the quasar to hit the red-emitting gas cloud outside.

$$GM_{\bullet} = f\, R_{BLR} (\Delta V)^2$$

Where G is the gravitational constant, $M_{\bullet}$ is the mass of the black hole, f is the form factor, R_{BLR} is the radius of the broad line region, and ΔV is the variation in velocity in the broad line region

Additional data were taken using a Baader Baches Echelle Spectrograph attached to a Celestron Edge 14 on a Losemandy G-11 mount. We attempted to use two different mounts, before deciding on the G-11, and we experienced issues with tracking via manufacture defects, such as an improperly manufactured cable meant to *talk* between the mount and guide camera. Additional issues arose from the wettest summer on record, including the wettest June and July ever in Massachusetts. CCDOps was the software used to take spectroscopic images, and PHD Guiding 2 was used for tracking. Tracking was of great concern given the issues in the past, but we were able to solve this riddle buyenlarge due to six weeks of adjustments, replacements, and adaptation.

Results

Our preliminary results show an initial peak followed by two more peaks in the form of a descending sawtooth wave. Each peak has a lower relative magnitude than the first as seen here through the I, R, and V filters. I filter peaks descend as follows: 12.083, 12.153, 12.21, relative magnitude is inverted and logarithmic. Meaningful spectroscopic data were not obtained due to weather and long exposure times necessary to receive enough signal. Observations this summer were severely hindered due to inclement weather, and exposure times for this target taking multiple nights. We are unable to observe Markarian 421 continuously, as we cannot observe during the daytime nor on cloudy nights.

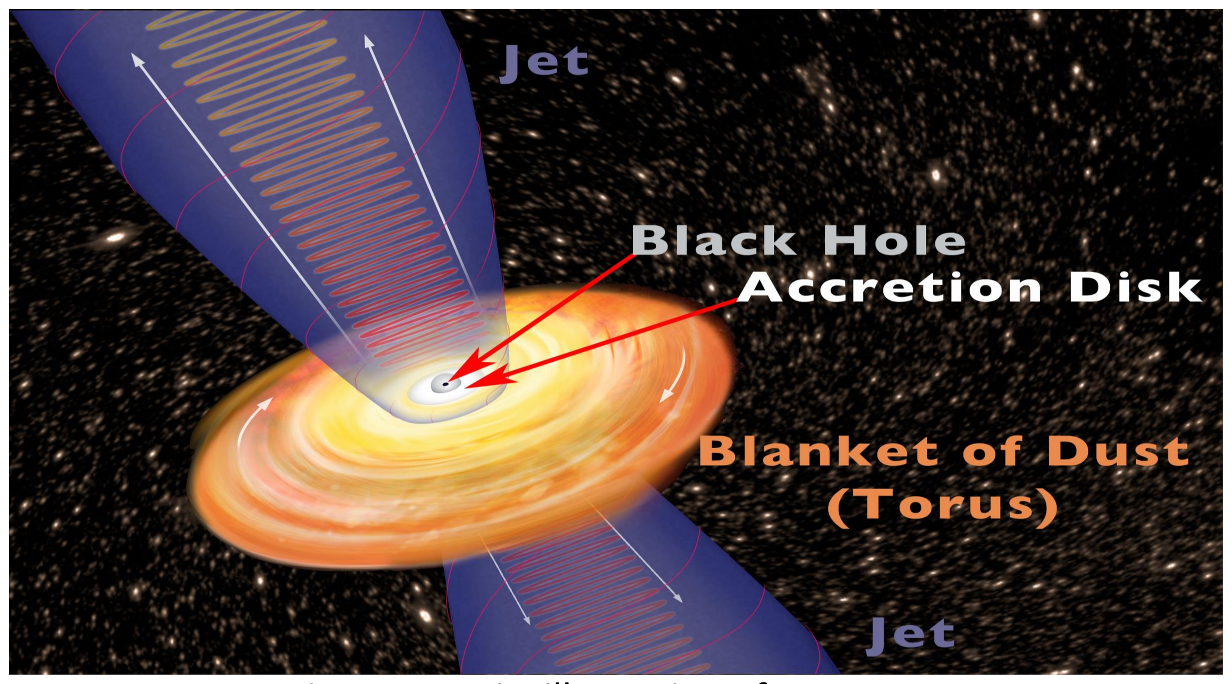


Figure 1: Artist illustration of a quasar

Figure 2(Left): Current telescope setup, calibrating pointing.
Figure 3(Right): Spectrograph with SBIG STF-8300M CCD Camera

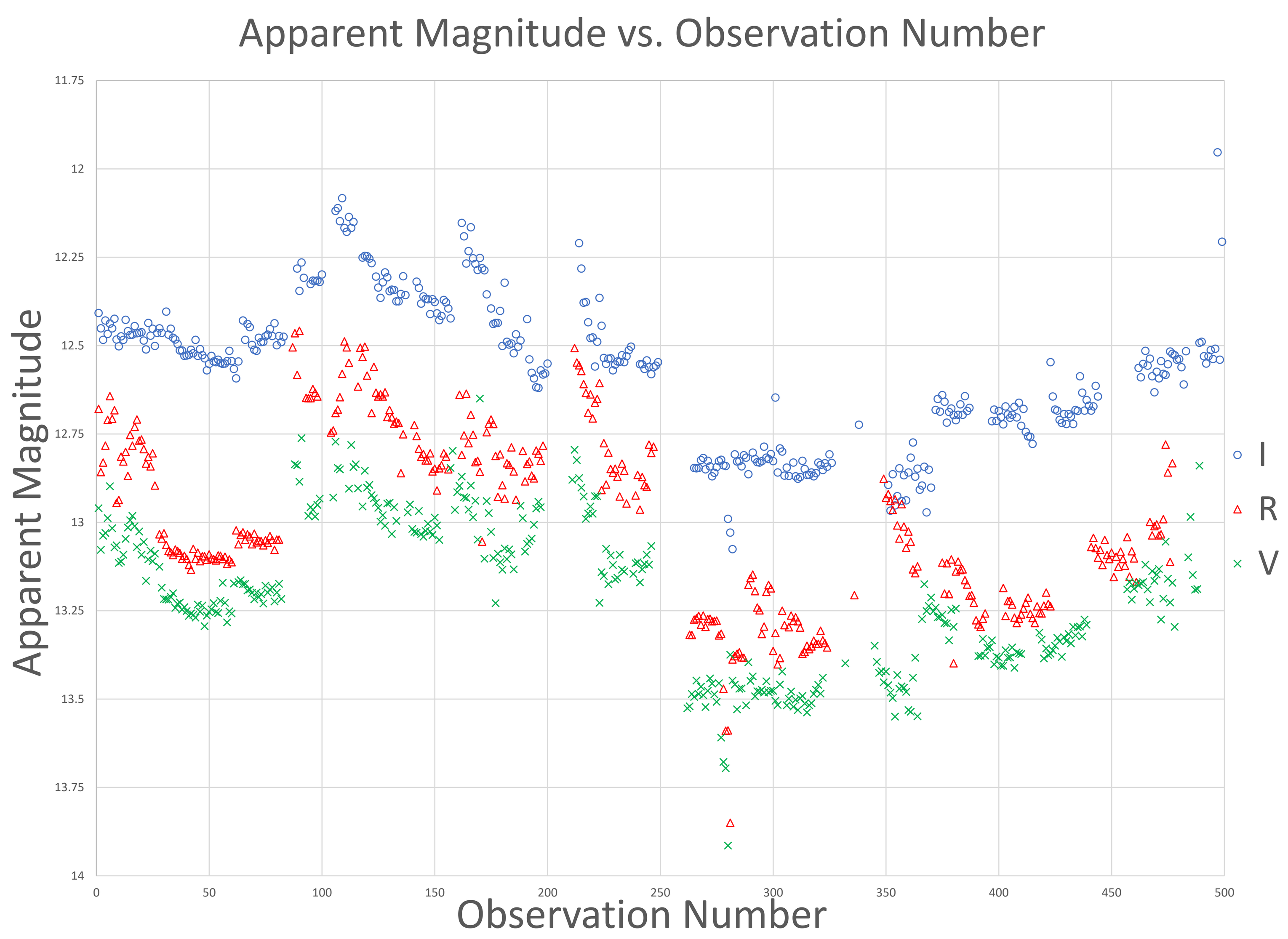
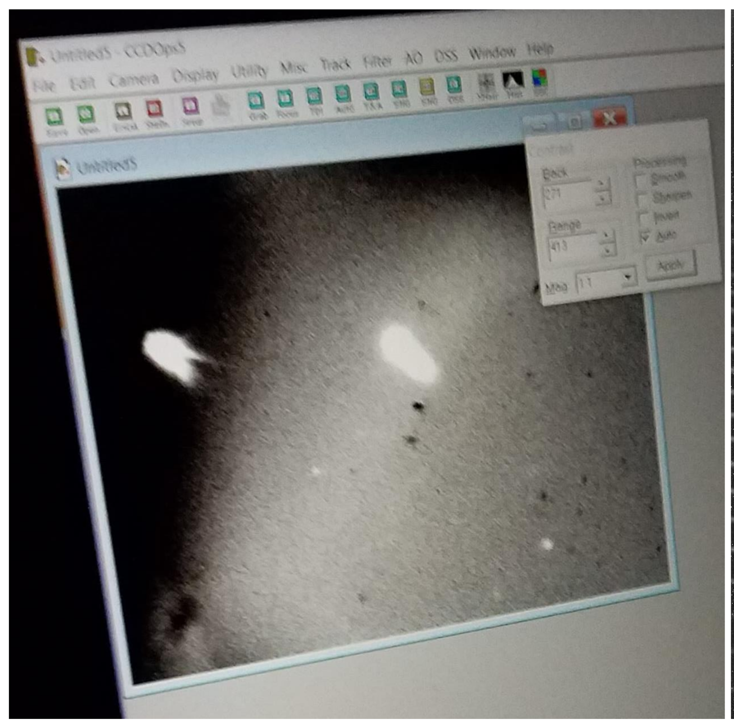


Figure 3: I, R, and V filter apparent magnitude versus observation number. To visualize all data, time between each observation is not to scale. Observations range from March 12th, 2021, to July 15th, 2021

Conclusion

We observed Markarian 421 from March 12th, 2021, to July 15th, 2021, and constructed light curves using that photometric data. Additional observations need to and are being made to compare data from multiple bursts for a more accurate measurement of the disk about this quasar, and other AGN targets to compare bursts and sizes. Spectroscopic research was attempted for this target but has not yet been successful due to weather and long exposure times. This June and July were the wettest on record in Massachusetts and severely hindered our ability to observe Markarian 421. To reduce our long exposure times and limit the buildup of dew, we decided to purchase a Celestron focal reducer and an Astrozap dew heater. More detailed analysis of the burst's different peaks and further observations should be piloted. Understanding the size of the disk, the speed of the gas within the disk, and the mass of the central supermassive black hole would provide great insight into the evolution of galaxies. Markarian 421 is one of the few quasars that exist today, and a better understanding of it may give us some hints as to why so few are still around and why this one has survived or was created.



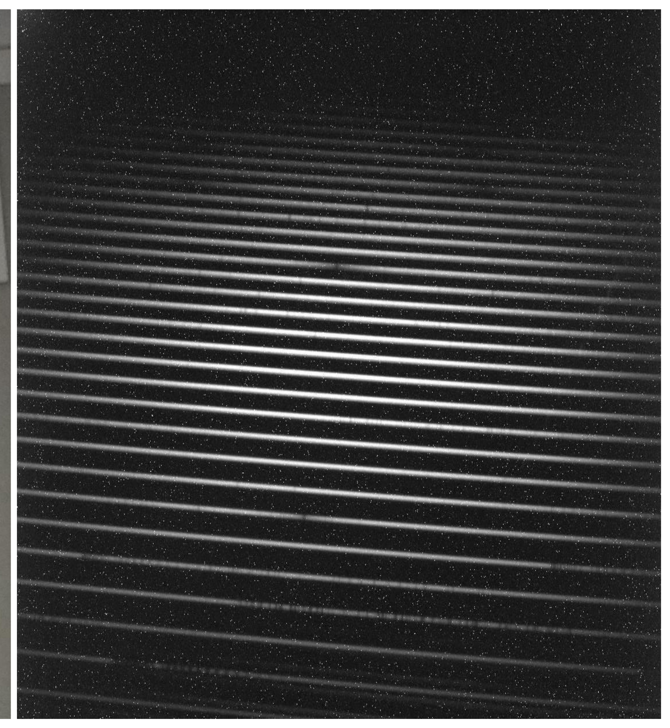


Figure 4(Left): Above is an image taken using the guide camera attached to the spectrograph. The small black dots just below the bright star in the middle are the two slits, and the bright object in the bottom right is Markarian 421.
Figure 5(Right): An example spectra taken of Mizar- middle handle star in The Big Dipper.

Figure 5: Markarian 421 is seen above with the green target labeled Mrk 421. This is a calibrated 320 second exposure 3x3 binned image through the Ha filter.

Acknowledgements

I would like to say thank you to the BEAR Team, Dr. Kling, the Adrian Tinsley Program, MASGC, and Professor Jamie Kern.

References

1. Merritt, D. (2013). *Dynamics and evolution of galactic nuclei*. Princeton University Press.
2. Bontà1, E. D., Peterson3, B. M., Bentz6, M. C., Brandt7, W. N., Ciroi1, S., Rosa5, G. D., … https://orcid.org/0000-0001-9191-9837, M. V. (2020, November 9). *IOPscience*. The Astrophysical Journal. https://iopscience.iop.org/article/10.3847/1538-4357/abbc1c.
3. Bentz, M. C. (2015, May 18). *AGN Reverberation Mapping*. arXiv.org. https://arxiv.org/abs/1505.04805.
4. *Quasar Regions*. (n.d.). NRAO. https://www.nrao.edu/pr/2012/almastarvinggalaxies/QuasarLabeled.jpg.