Annual RFO Research Report 2023

Overview

The RFO Research Committee was established in the Spring of 2021 by then Executive Director, Chris Cable and SSU Professor Laura Peticolas. That was the seed that has turned into the 2023 RFO Research Committee and this report summarizes the impact of the work accomplished by the committee members during the current year.

The goal of the Research Committee is to support docents and students in learning how to do astronomy science using both the instruments available at RFO as well as instruments available for public use remotely. All areas of research are welcome and the committee meetings and observing sessions at the observatory are used to teach, learn, develop skills, increase understanding and, in some cases, to publish the results of the work that is being done.

During 2023, the Research Committee was able to:

- Deliver training on how to do differential photometry, that is, how to make scientific measurements of the brightness of stars by calibrating their images against comparison stars with known brightness.
- Improve the capability of the main science instrument at RFO, the Ritchey-Chretien 20-inch telescope (RC20). This work included solving multiple operating issues, improving operator instructions, replacing failing equipment, such as the filter wheel, and acquiring new cameras to support public astronomy as well as scientific imaging.
- Reach out to students in the community to give them opportunities to interact with docents in the Research Committee and to do their own projects to serve their education needs in their own schools.
- Make observations of target stars for science. The group chose targets that were interesting to them and to the community of variable star observers (AAVSO). They organized observing sessions and took images in a way that they could be used for scientific analysis by themselves or others.
- Develop software to support research. During 2023 team members developed software that organized and made searchable the many images acquired by the observing team, saving them in more accessible computer storage for group search and use. A team member wrote a custom differential photometry light curve analysis program in Python. Other team members have written software that supports and enables research work on the images acquired by the observing team.
- Train committee members and others on how to do astronomical research with the equipment at RFO and with remote observatories that open their instruments to public access.

The Research Committee looks forward to an equally productive 2024.

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Observing for Research

Observation Target List

Established a target spreadsheet inside the East Wing Log spreadsheet. Added Cepheid variables as well as additional cataclysmic variables (CV) and R Coronae Borealis (RCB) stars. A total of 817 science images were taken during sessions across 2023 by multiple observers.

Target	**Observations**
AP Her	10
AP Her	6
EP Lyr	12
HH Per	8
NSV11154	4
SS Cyg	98
SW UMa	32
TT Oph	59
U Gem	106
V Vul	79
V0504 Per	37
V1226 Her	62
Z Aur	52
Z Cam	125
Z Dra	10
Z Umi	117
Total	**817**

Remote observing at Las Campanas Observatory (LCO)

Variable stars U Gem, Z Cam, Z Aur, Z UMi and SW UMa were observed thanks to observing time provided by Rachel Freed's observing time grant for her student programs.

Calibration

First calibration images were taken in July 2023. Bias, dark and flat frames were taken to calibrate the science images we were taking. The observers struggled to get good dark frames due to a bug in the Atik16200 that causes the shutter to not fully close during a dark frame, admitting stray light in the observatory onto the image. Good dark frames for all of the science

frames were finally taken in December 2023 and additional dark frames have been taken to match all of the exposure times for science frames taken in 2023. The next step is to apply the dark, bias and flat frames to the science images to calibrate all of them.

Differential Photometry

SS Cyg Light Curve

John Gregg reported doing differential photometry with JS9 on 59 uncalibrated images of SS Cygni producing a light curve from the data. SS Cygni is a variable star in the northern constellation Cygnus (the Swan). It is the prototype of the subclass of dwarf novae that show only normal eruptions. It typically rises from 12th magnitude to 8th magnitude for 1–2 days every 7 or 8 weeks. (Wikipedia)

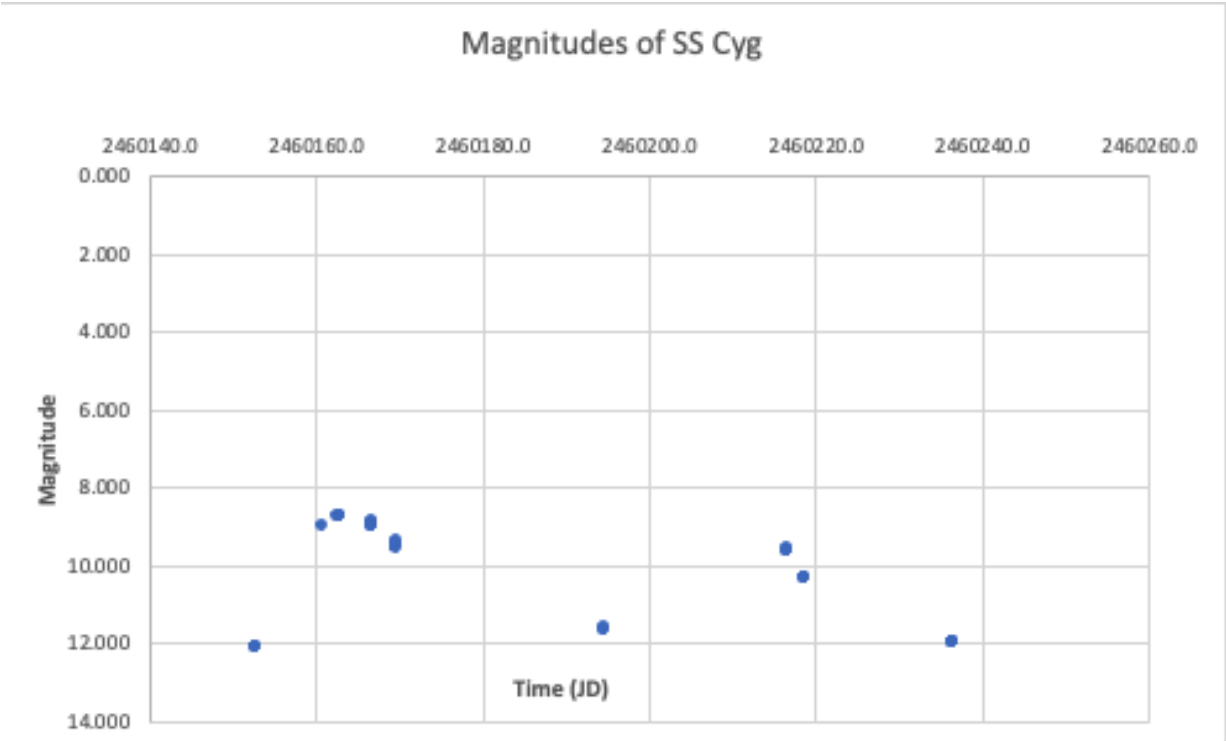
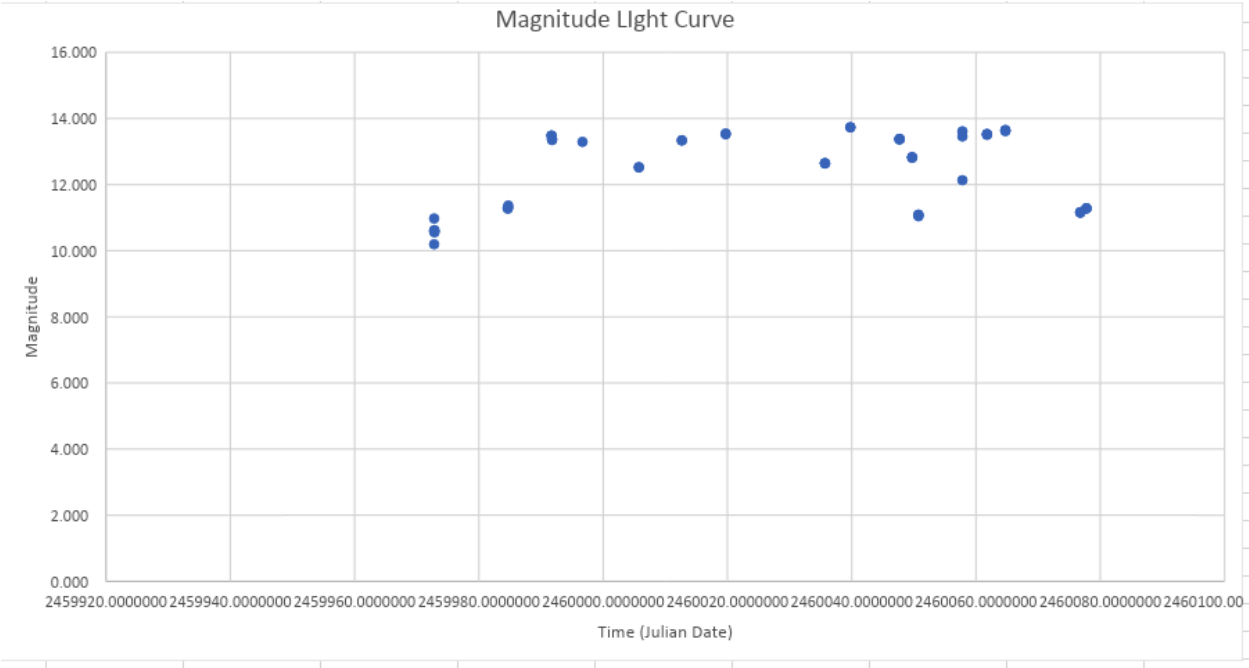


Figure 1

Z Cam Light Curve

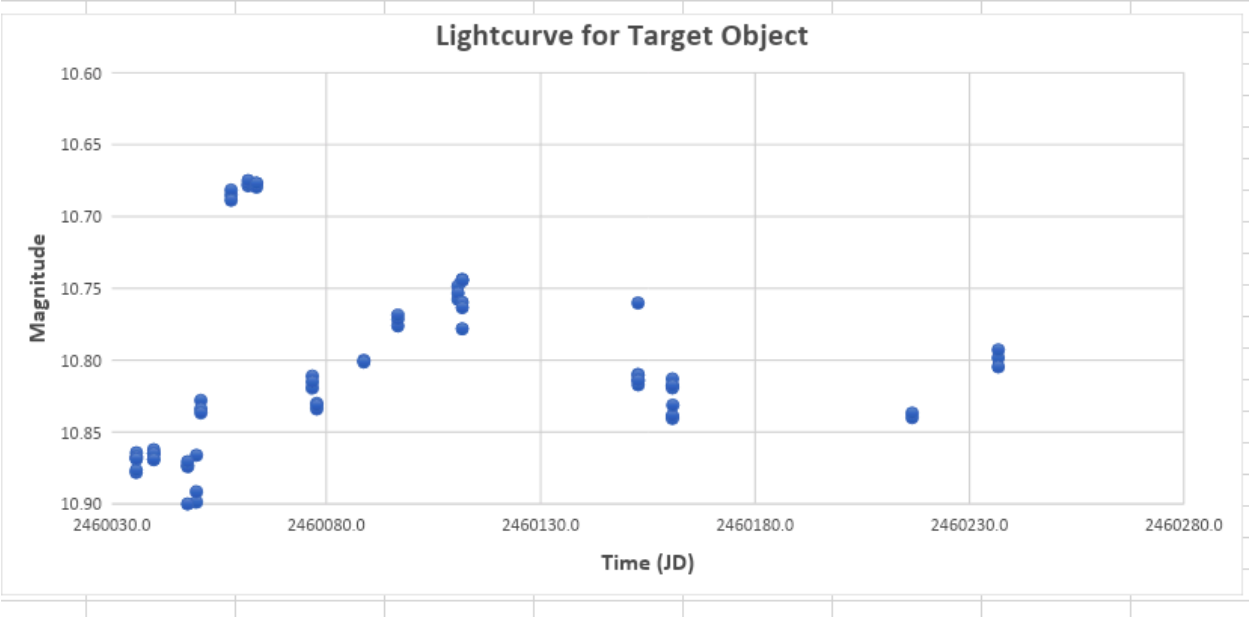
John Gregg reported doing differential photometry with JS9 on 50 uncalibrated images of Z Camelopardalis producing a light curve from the data. Z Camelopardalis (Z Cam) is a cataclysmic variable star system in the northern constellation of Camelopardalis. It has an apparent visual magnitude which varies between 9.8 and 14.5. This system is the prototype star

for the family of Z Camelopardalis variable stars: dwarf novae with standstills at a brightness intermediate between their maxima and minima.[2] It may be the same bright nova that was recorded by Chinese astrologers in the autumn of 77 BCE. (Wikipedia)



Z UMi Light Curve

John Gregg reported doing differential photometry with JS9 on 71 uncalibrated images of Z Ursa Minoris producing a light curve from the data. Z Ursae Minoris (Z UMi) is a carbon star and R Coronae Borealis variable in the constellation Ursa Minor. Z Ursae Minoris was discovered to be a variable star in 1934.[7] It was catalogued as a probable Mira variable, due to its red colour and variations over several hundred days.[8] It was discovered to be a carbon star in a survey published in 1985,[9] and subsequently found also to be hydrogen-deficient.[7] After fading by almost six magnitudes in 1992, it was classified as an R Coronae Borealis variable.[10] It was confirmed as an R Coronae Borealis variable, one of the coolest in the class, after its spectrum was analysed in 2006. (Wikipedia)



George Loyer also did differential photometry of Z UMi with AAVSO VPHOT software from uncalibrated images taken April through October 2023. A total of 117 images were available and the resulting light curve uses all good images from that set. The plot shows the V band filter in red and the I (infrared) band filter in blue. The variation in V is consistent with other R Corona Borealis (RCB) stars when not in a large magnitude event, with periods of 40-50 days and brightness variations of 0.2 magnitudes or less. The I band measurements did not show much variation, an interesting result since the star is actually brighter in infrared than in V band, as are all RCB stars, due to the dust cloud of carbon particles that surround them.

The work to produce this light curve (learned in the AAVSO VPHOT class) included:

- dropping images that had issues in the exposure,
- choosing a set of comparison stars (10) and a check star (1),
- stacking images that were taken on the same night within an hour of each other to reduce signal to noise ratio (SNR),
- processing the images with a Python program that submitted the images in batch mode to the astrometry.net site for computing the World Coordinate System (WCS) coordinates (facilitates stacking and is also known as plate-solving), and then
- creating the light curve for the two filters.

The resulting data set is then available for export to present in Excel or other software.

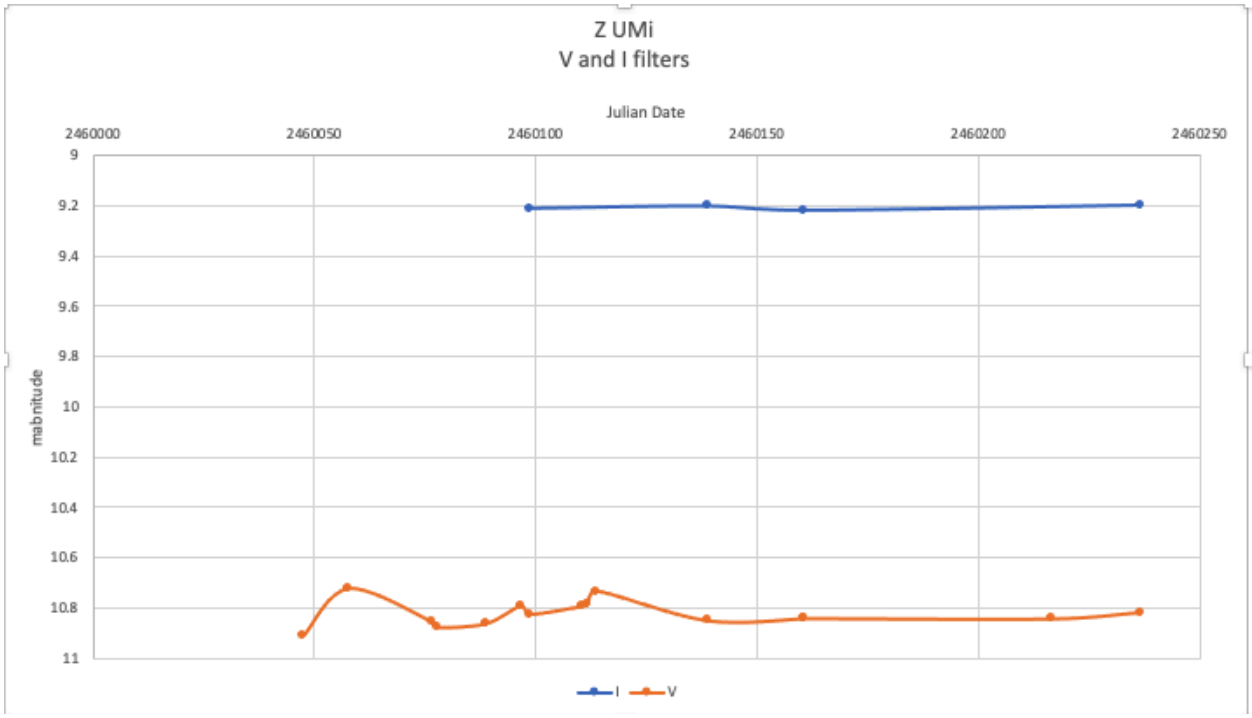


Figure 2

Research Instrumentation and Support

The work on the instrumentation in the Robert Ferguson Observatory can be divided into New Instrumentation, Maintenance and Troubleshooting and Support Work. Research is done only on the RC20 telescope in the East Wing of RFO, so the instrumentation work all refers to that telescope in the East wing of the observatory.

New Instrumentation

Filter wheel

The main ATIK16200 camera is mounted on a filter wheel which is mounted on a Perseus multi-port adapter which is attached to the prime focus port of the RC20 telescope. The filter wheel has nine slots and each slot contains a flat filter that is either used for astrophotography or for science images. The filter wheel was replaced in June of 2023 due to intermittent problems experienced with the original filter wheel that came with the telescope from USF. Failure to move was the most frequently reported problem. The new filter wheel had been purchased in a previous year so it was put into service, solving the intermittent operation problem.

Research Camera

A new cooled monochrome CMOS research camera was purchased with a $3,000 grant from the New York Community Trust. The ZWO ASI2600 Pro USB3.0 Cooled Monochrome Camera was proposed by Gordon Spear and approved by the board for purchase. The new camera has improved specifications over the current ATIK16200 camera, most important being Quantum Efficiency of 92% compared to 48%. This is a CMOS camera, and download speeds will be very fast over the USB3 data port. Pixels are about half the size of the ATIK16200 so we will likely bin at 4x4 instead of 2x2 with no loss of resolution and improved noise figure. The camera will be installed as a replacement for the Atik16200 attached to the nine-port filter wheel.

In addition to the new research camera, Spear used the remaining grant funds to purchase a Star Analyzer Grating 100 and Star Analyzer Grating 200 with associated adapters and software that will fit in the filter wheel, replacing the less frequently used H-alpha filter. These gratings will allow us to take research spectra of low dispersion to identify specific stellar types by spectral type as a beginning exploration of doing spectral analysis with the RC20, an expansion of our research programs. Installation of the new camera will take place early in 2024 once calibration image work has been completed with the Atik16200 to allow all of the 2023 science images to be calibrated.

Astrophotography and Public Observing Camera

A new cooled color CMOS camera was purchased with docent-sourced funds. The ZWO ASI294MC Pro Color Cooled Astronomy Camera was proposed by Brian Kellogg who also worked with other docents who frequently volunteer on the RC20 to raise the funds for the camera which cost about $950. We expect the camera to be very useful for public nights where we can take live color photos rather than the current monochrome photos we are able to show. The camera will attach with an adapter to one of the Perseus multi-instrument ports. The camera was installed in December 2023 and operator instructions have been updated to use the new camera at public star parties.

Spectrograph

One of the long term goals of the Research Committee is to acquire a spectrograph to be used with the RC20 to add that capability to our research. Depending on the spectrograph chosen, the spectra studied could be broadband for stellar classification or high resolution and smaller bandwidth to study doppler shifts for analyzing star clusters or to follow up potential exoplanets from TESS and other space observatories.

The spectrograph design has to be matched to the RC20 telescope to make best use of both the telescope capabilities and the spectrograph capabilities and the proposed purchase has to be within the RFO equipment budget. Commercial spectrographs are generally not suitable for RFO as they are in the $50,000+ range, but the instruments intended for amateurs offered by Shelyak Instruments have been considered for suitability and cost in this project proposal.

George Loyer and Gordon Spear are collaborating on a proposal to acquire a Shelyak motorized UVEX spectrograph which meets all of these requirements. The acquisition time depends on the availability of funding and the preparation of the research team to begin observing and analyzing stellar spectra.

Maintenance and Troubleshooting

Infrared (I) filter “swoosh” in images

Multiple observations were recorded of what appears to be a light leak that is visible only in the Infrared (I) filter of the UBVRI filter set. A search for the source of the light leak identified possible culprits at the filter wheel and at the interface to the exit port of the RC20. Work on dark frames resulted in determining that the light leak was present in ALL filters, but was just not as visible in filters other than the infrared. Getting good dark images without light leaks is now seen as the solution and we expect that the improved dark images will allow calibrated images to be used without the visible “swoosh”.

Filter wheel intermittent operation

Maintenance work was conducted on the filter wheel when problems moving it to a new position were exhibited. Lubrication and fine tune adjustments all failed to keep the problem from recurring. The problem was solved by replacing the filter wheel in June 2023.

Pointing accuracy issues

A TPoint run in 7/2023 has resulted in much improved pointing accuracy. Open loop slews are coming to a target within a few arcminutes reliably. Unguided exposures of 3 minutes are achievable now.

Dark frames spoiled by open shutter

Dark images are being spoiled by shutter opening during the exposure. This is a known bug with SkyX and ATIK16200 cameras. Switching to Maxim DL allowed dark images to be successfully taken. Further work in December 2023 identified ambient light sources in the observatory that were spoiling the dark frames and an observing team was successful in taking good quality dark images of any exposure time with changes in observing practice to eliminate ambient light.

Focus settings not stable

Focus settings were reported to not remain where set between observing sessions in November 2023. Testing is continuing to identify the source of this intermittent problem.

Support Work

Imagelib repository and search tool

Dave Kensiski released the first version of ImageLib in July 2023. RFO users (anyone with an rfo.org Google account) can download images from all of those taken with the RC20 on a web site at https://imagelib.rfo.org. This software was designed to provide easy access to images taken on the RC20 telescope, whether they are science images or astrophotography images.

The software displays images that have been copied from the observatory operator workstation after a few hours' delay to a cloud server. Research operators need no longer copy images to the Wiki or take them home on their thumb drive, and researchers who are analyzing but not acquiring images have easy access for their work. Astrophotography done on the RC20 for specific targets are as part of an event at the observatory are all available at the web site the next day.

The images that are transferred to the cloud server are detected by the ImageLib software and presented as thumbnail images organized by the date of the image. While you can just use the Next and Previous buttons to scan through the images, there is also a search function provided that allows the user to search by partial object name or by partial date. The user can then select one or more images from the search results and download them to their own workstation. The images that are downloaded are in the FITS file format, an astronomical standard, which contains the image and a header filled with details of the state of the telescope and camera for that image. Curious users can view the FITS file using any FITS viewer, including one provided by the developer of the ClearSky app, Elwood Dowd, on the web at https://www.clearskyinstitute.com/fits/. Alternatively, users can click on the thumbnail to display the full size image on the web page and then do a screenshot to capture the image for their use.

Dave also released bug fixes and improved search features for partial word matches and search suggestions in September 2023. The code is stored on GitHub and bugs and feature requests can be reported as issues in the GitHub project. The software has proved essential for researchers to find the images they wish to use for differential photometry analysis and for collaborative troubleshooting of image and telescope problems during the process of acquiring both science and astrophotography images.

Training

Members of the group provided and found training that furthered the goals of the Research Committee.

- RC20 operator. Multiple team members took refresher operator training on how to operate the RC20 so that they could run observing sessions for science images.
- JS9 software for differential photometry. Gordon Spear provided multiple training sessions during committee meetings on how to use JS9 to do differential photometry.

Members used the training to do differential photometry and to work with high school students for their own senior projects.

- VPHOT class taught by AAVSO. George Loyer took the AAVSO CHOICE class on VPHOT and used the material to generate a light curve for Z UMi from RC20 science images.
- Light Curve classification class taught by AAVSO. George Loyer took the AAVSO CHOICE class on variable star light curve classification, which was his introduction to a variety of variable types and sparked interest in R Coronae Borealis stars.
- AAVSO webinar on how to measure variable stars. Multiple members attended the AAVSO webinar on how to measure variable stars.
- Flats, darks and bias frames. Gordon Spear taught a session during a committee meeting on the purpose of calibration frames and the details of how to take darks, bias and flat frames. He is working with multiple members to take good calibration frames to be used with the science images taken during 2023 using the Atik16200.
- Basics of astronomical spectroscopy. Gordon Spear taught a short session on the basics of astronomical spectroscopy to introduce concepts in preparation for the acquisition of a spectrograph for the RC20.
- SuperWASP. Gordon Spear taught a session on what the SuperWASP project is and how to participate in this citizen science crowd-sourced application for examining and classifying light curves that are acquired automatically by a survey telescope.

Outreach for Student Focused Research

Confirming RCB IR Excess with AllWISE and 2MASS

George Loyer and Adithya Vasudavan, IR Excess paper. Paper submitted to JAAVSO and peer reviewed, currently being revised. This paper intended to validate that all of the R Coronae Borealis (RCB) stars in the AAVSO VSX database of variable stars exhibit the IR excess noted in papers by Clayton (G. C. Clayton 2012; Geoffrey C. Clayton 1996) and Tisserand (Tisserand, Clayton, and Welch 2018). The paper takes the approach of comparing the known RCB stars from both VSX and the papers of Clayton and Tisserand and comparing their infrared brightness in scatter plots to the infrared brightness of a random sample of 200 stars. The infrared brightness data was extracted by Vasudevan from the 2MASS and WISE infrared survey projects that contain infrared brightness data in the J, H and K bands (2MASS) and the W1, W2, W3 and W4 far-infrared bands (WISE). Additional BVRI data was extracted from the VSX database by Vasudevan, who also wrote a Python program to plot the scatter charts. The plots show that the RCB stars are significantly brighter than the randomly selected stars.

The referee feedback was a request to place the work in the context of much more work done to establish the existence of IR excess in RCB stars, and the character of that excess, specifically in the work by Feast (Feast and Glass 1973). Those revisions are in progress.

Double Star Observations

Rachel Freed taught a Double Star Science class for high school students (Fall 2023). The class was funded by the Astronomical Society of the Pacific. Thirty-eight students signed up from all over the world. Students learned how to choose a double star for study from the Washington University double star catalog, how to schedule Las Campanas Observatory (LCO) remote observations to image the double stars, how to use AfterGlow to analyze the images downloaded from LCO and how to write their paper for submission to the Journal of Double Star Observing for which Rachel serves as editor.

Differential Photometry Using LCO Remote Observatory

Marin Academy students Noah Laney and Hayden Stone did differential photometry on Z UMi using images collected from LCO during April and May. George Loyer, assisted by Gordon Spear and Rachel Freed coordinated the work with Rachel's LCO privileges. Laney and Stone learned to create and download observations from the LCO network, and to use JS9 to do differential photometry on those images. They had enough images to get a short light curve and presented it to their classmates and teacher in fulfillment for a senior project requirement.

Impact of Light Pollution on Astronomy and Ecosystems

Felix Venancio from Colusa High School is working with mentor George Loyer to study the impact of light pollution on astrophysics and ecosystems. This project extends through the Spring of 2024 and is in start up phase.

Research Publications

Confirming RCB IR Excess with AllWISE and 2MASS

George Loyer and Adithya Vasudavan, IR Excess paper. Paper submitted to JAAVSO and peer reviewed, currently being revised.

Double Star Observations

Multiple papers submitted by students to the Washington University Double Star Catalog.

Other Work

Z Cam

- U Gem, Z Cam - John Gregg, Brian Kellogg, David Cranford

- Z Cam revised analysis (5/2023), John Gregg.
- Z Cam revised analysis (6/2023) John Gregg.
- Revised Z Cam analysis with 70 pixel circle (9/2023) John Gregg. Light curve shows that there were at least three events for this CV.
- Pending calibration of images, light curve analysis will be repeated and submitted to AAVSO.

Adding RC20 as a standard telescope in VPHOT

AAVSO has a feature where a standard telescope can be created in VPHOT so that the details of the telescope needn't be added each time observations from that telescope are used. Phil Sullivan and George Loyer corresponded with the VPHOT staff and considered multiple possible ways to set up RFO's RC20 telescope as a standard for RFO researchers to use. In the end, the feature required frequent changes because of the way that RFO works and the changes would have to be manually updated by the AAVSO VPHOT staff, so we decided to simply keep a copy of the configuration in local files and ask researchers to use the local standard to submit their observations to AAVSO.

JS9 Photometry Aperture Study

John Gregg ran a study of the effect of the size of the aperture used in JS9 for photometry on the resulting magnitude estimate. He found that for the particular images he chose to analyze an aperture size of 20 pixels was the best at both including all of the data and at excluding nearby contamination from other stars. This aperture size would have to change based on how the star size changes from image to image, but in a series of the same exposure length, the same aperture should be used for the full analysis of the light curve.

Custom Python Image Analysis

Judd Reed wrote a Python program to analyze raw images, find comparison stars and do differential photometry, and produce a light curve in one pass. George Loyer used the program to analyze images collected of Z UMi.

SS Cygni

John Gregg analyzed 59 uncalibrated images of SS Cyg, a cataclysmic variable star, and created a light curve in November 2023.

Z UMi

George Loyer analyzed uncalibrated images of Z UMi, an R Coronae Borealis variable star, and created a light curve in November 2023. He used VPHOT to analyze over 80 images. He dropped images that had exposure issues, used astrometry.net to set WCS coordinates for the

rest of the images allowing them to be stacked as needed, and created a light curve for both V and I bands.
He is working on a Python-based analysis pipeline to incorporate calibration images (bias, dark, flat) into raw images on the AWS-hosted repository for future analysis efforts and submission of data to AAVSO.

Research Committee

The RFO Research Committee meets monthly via Zoom on the fourth Monday. In addition to meeting as a committee, there were frequent observatory sessions for observing, instrumentation changes, software installations and maintenance and training.

Active members of the Research Committee, in alphabetical order, are Katherine Bradley, Joseph Byrnes, David Cranford, Byron Durkee, Rachel Freed, John Gregg, Brian Kellogg, George Loyer, Ryan McDaniel, Marek Mierzwinski, Michael Papaik, Evelyn Eowyn Parks, Judd Reed, Gordon Spear, and Phil Sullivan. George Loyer organized the Zoom call and the agenda for each meeting and recorded a report to the board from each meeting.

Annual Report submitted by George Loyer, committee chair.

References

Clayton, G. C. 2012. “What Are the R Coronae Borealis Stars?” *Journal of the American Association of Variable Star Observers (JAAVSO)* 40 (June): 539. https://doi.org/10.48550/arXiv.1206.3448.

Clayton, Geoffrey C. 1996. “The R Coronae Borealis Stars.” *Publications of the Astronomical Society of the Pacific* 108 (March): 225. https://doi.org/10.1086/133715.

Feast, M. W., and I. S. Glass. 1973. “Infra-Red Photometry of R Coronae Borealis Type Variables and Related Objects.” *Monthly Notices of the Royal Astronomical Society* 161 (January): 293. https://doi.org/10.1093/mnras/161.3.293.

Tisserand, P., G. C. Clayton, and D. L. Welch. 2018. “Tracking down R Coronae Borealis Stars Using the WISE All-Sky Survey.” https://doi.org/10.48550/arXiv.1809.01474.