SURF 2017 Final Report

Project Title: CIBER2 Automated Optical Focus Calibration System

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Abstract

The Cosmic Infrared Background Experiment (CIBER1) was a sounding-rocket probe experiment created to study infrared background light from above the Earth's atmosphere. A vital aspect of this experiment was assuring that the detectors were placed accurately at the correct focal position of the instruments. In the CIBER1 focusing procedure, a knob and a micrometer turned by hand was used to adjust the focus position, an incredibly tedious and tiring process once repeated multiple times. This is the functionality I was assigned to upgrade for CIBER2 measurements, automating the previously manual task and decreasing the time for the measurement from approximately 2 days to barely 2 hours. To implement this function, a precise, remotely controlled stepper motor to scan a pinhole through a collimator's focus was purchased, along with a relay device implemented into a simple circuit used to communicate with the CIBER2 data acquisition system. A Python program and GUI was written to control the Moonlite Mini Controller stepper motor and relay device, thus automating the movement for a scanner given a set of input parameters.

Background

CIBER is a sounding-rocket experiment which studies near infrared background light from above the Earth's atmosphere using fluctuation studies and absolute spectro-photometry. Between 2009 and 2013, CIBER1 was flown a total of four times containing a suite of four separate instruments. With the success of CIBER, CIBER2 is currently being constructed as the next generation experiment. The new detectors will contain a 28.5cm primary aperture, allowing for more sensitivity than CIBER, as well as expanded spectral coverage. To take measurements, the CIBER 2 detectors need to always be at the focus of the optics to a high degree of precision (30 microns). In CIBER 1, these detectors were focused by scanning a pinhole throw a collimators focus and taking measurements by hand. The basic optical focusing arrangement is depicted to the right in **Figure 1**. Scans, or exposures were taken at different positions by displacing the pinhole with a knob and sending a message to the experiment to capture an image. The data from these exposures along with the various positions were used to calculate an adjustment distance. In **Figure 1**, this offset is represented by the double sided arrow above the pinhole, as well as the one to the left of the 2 detectors. An optically calculated scaling factor, or ratio was applied to this offset to figure out how much to exactly refocus the detectors.

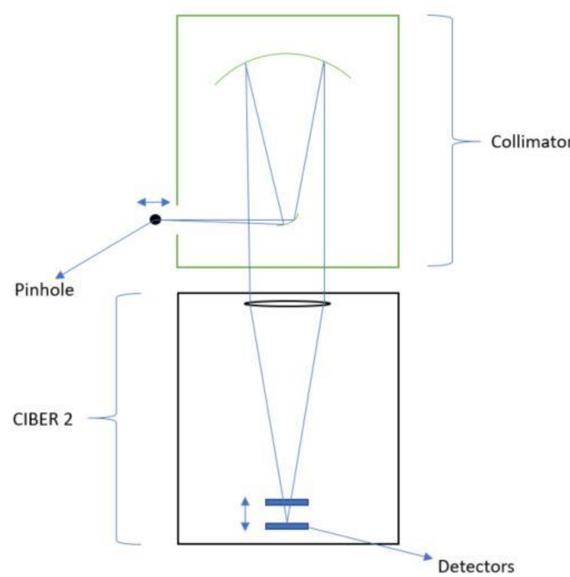

Figure 1: *Collimator and CIBER Optical Arrangement*

Findings

Launching in 2018, CIBER2 will study fluctuations in the Near-Infrared (NIR) background in 6 bands from 0.5 to 2.0um. An important aspect of this experiment is assuring that the detectors are placed accurately at the correct focal position of the instruments. During laboratory testing for CIBER1, instruments were focused by viewing a source through a vacuum window. The source was generated using an off-axis reflecting telescope as a transmitter by placing an 8 μm pinhole at its prime focus, projecting an unresolved source to infinity. The focus is measured by scanning the pinhole precisely through the collimator's focus position. If the CIBER detectors are correctly placed at the focal plane, the best observed point spread function will be measured when the pinhole is at collimator focus. If corrections need to be applied, the pinhole position during the optimum measurement (**Figure 2)** will inform the user how and what adjustments need to be made.

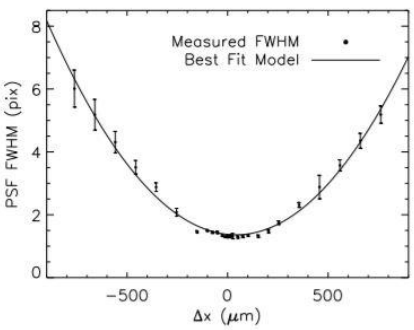

Figure 2: *Scan Best Fit Model*

Taking scans at several positions was a manual process. One person would be adjusting a collimator knob while telling the other to take an exposure from the computer. These scans were meticulous and took nearly a week. It was an inconvenient and painful process. The 10 week task I was assigned was creating the tools to upgrade this instrument focusing process. By the end of the summer, I found how much my work expedited the previously long process by nearly a day to hour ratio.

Methods

To solve the issue of a manual focusing arrangement, the simplest solution was to automate the entire calibration and focusing system. To take the actual scans, a simple relay device was used. When the relay was switched on, a pulse from a 5V power source would be sent to the experiment electronics to set an exposure. To indicate the status of the relay, an LED is connected within the circuit. To implement the relay into the circuit, I drew up a simple circuit diagram which would take a 5V DC power supply as input, and would output into a cable. My program connected with the relay via a USB port provided on the device itself. We drilled holes in a plastic enclosure that was purchased to mount the breadboard and relay device (**Figure 3)**. 3 holes were created to allow the input / output wires (USB, 5V power supply, coax), and an additional 8 smaller holes to mount the circuit elements.

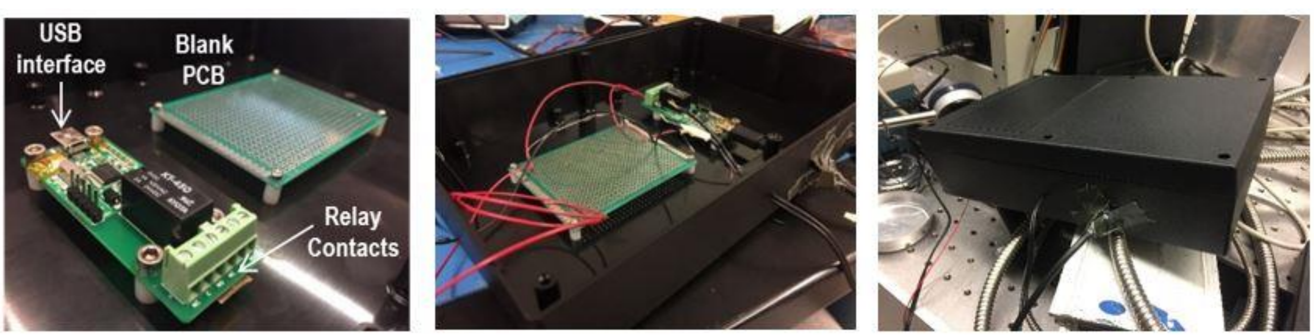

Figure 3: *Steps 1, 2, 3 of Relay Circuit Setup*

The focusing process was previously conducted by vocally communicating when to take an exposure to another person sitting next to a computer. To automate the knob dial movement, a stepper motor was purchased to displace to different positions with various step sizes.

The stepper motor purchased was a Moonlite Mini V2 Stepper Motor with precision up to 0.00008 inches / half step. The relay device purchased was a simple single channel USB powered relay module with 2 inputs. The calibration program which I developed was written in Python, using the packages pySerial, pyQt, Matplotlib, and Numpy. pySerial was used to communicate with the relay device and motor, and pyQt was the graphics library used to design the user interface itself. I utilized Matplotlib to plot the pre-scan simulation graphs, and Numpy minimized the code used to crunch the position data sets for the pinhole path.

Data Gather and Scanner Module:

The data gather module was perhaps the most important part of the program. It was responsible for collecting all the data required to run the several sub-processes of the focusing system. The parameters it took in were the: center (best focus position), fine steps range, number of fine steps, course steps range, and number of course steps. The algorithms generated a positive and negative position set by merging the course and fine lists, sorting, and then removing the duplicates. This method was repeated for the negative direction with the negative ranges. Additionally, this module used a simple averaging equation to calculate and generate the simulation plot coordinates.

The scanner module was responsible for executing the movements calculated by the data gather module. The pinhole moves all the way to the positive maximum, and returns to the best focus position with a combination of specified course and fine steps. After each step, an exposure is taken for a certain amount of time. The process is then repeated for the negative side, after which it returns to the best focus position, and the scan is complete. Many of the functions called to carry out these sub processes were written with the pySerial module.

Simulation Plot:

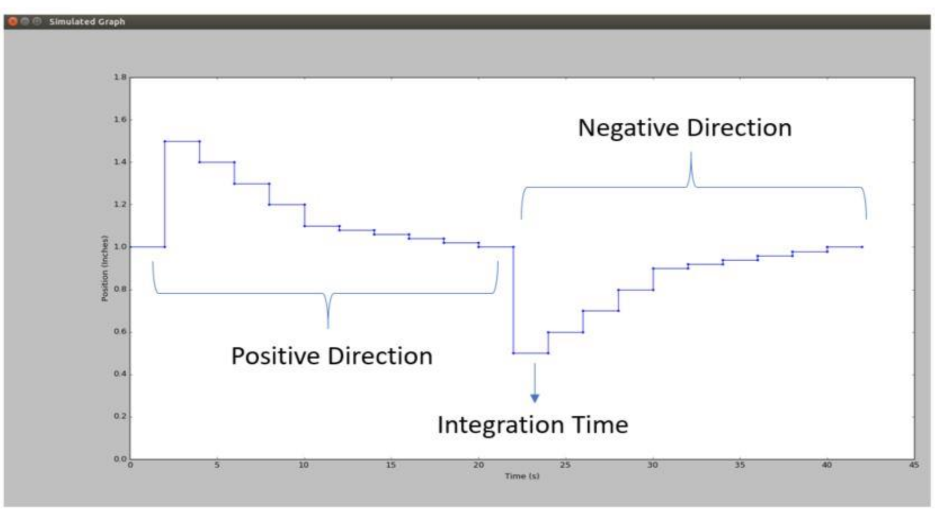

Figure 4: *Pre-scan Simulation Graph*

The simulation plot **(Figure 4)** is a visual representation of the scan before it is ready to run. The user can see the steps taken, the length of the integration time, and the overall journey of the pinhole over a Position vs Time graph.

GUI (Graphical User Interface) Module:

The user interface created to operate the automatic focusing system contains several functionalities. The diagram below (**Figure 5)** indicates each, explaining its role in the system. The "Focus / Stop / Reset" feature allows the user to focus the pinhole to a certain focus position without running a full scan. The Stop button halts all motor movement, while the Reset button sets the pinhole back to its original absolute 0 point. The "Plot simulator" button executes the pre-scan simulation graph given the input parameters of the scan, located right above it. If the desired graph isn't produced, modifications can be made to the parameters to generate the desired scan.

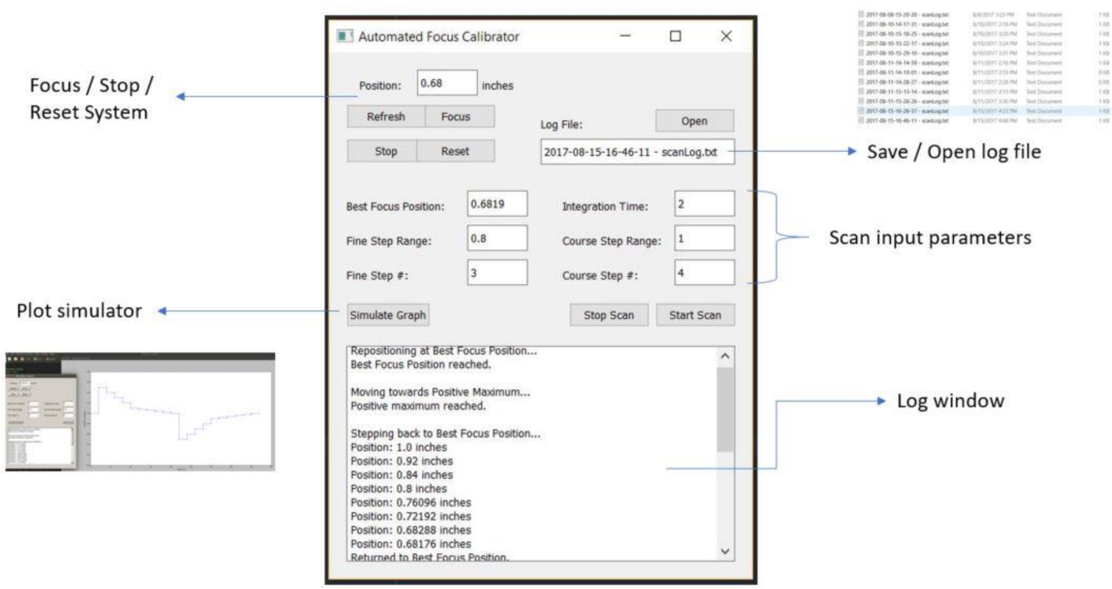

Figure 5: *User Interface Diagram*

On the bottom of the user interface is a Log window, responsible for keeping track of all tasks running on the program. Every sub-process is logged into the window, and most importantly, the scan itself. As displayed in Figure 5, every step of the scan is documented inside the window. The ongoing background thread sends a message to the GUI every time a displacement position for the positive or negative data set is reached. Above the Log Window and Input Parameters is an option to save the log file, with its file name set by the time the scan was administered. Rather than copying the entire Log Window into a text file, the log file is updated simultaneously with the window after each steps of the scan or sub-process. This way, any program crash or malfunction can be diagnosed by opening the saved log file to see where the most recent documentation occurred.

Conclusion

The Automatic Calibration System I was responsible for designing for the past 10 weeks will hopefully expedite the previously tedious process of focusing instruments before launch. I developed the program on my Linux system and completely transferred a robust version of the application onto the Windows system used in the lab. To the right (**Figure 6)** is an elementary setup of all components in the experiment setup. These components consist of the relay circuit to take exposures, the laptop running the automated focusing program, the collimator to focus the telescope, and the actual telescope (CIBER 2). Future work in this project includes the actual exposure data analysis of the images taken during the scan. Algorithms developed by my co-mentor will help parse the exposures which were captured during the integration times of the automated focusing calibration system. Along with my developed scanning program, this data analysis will complete the focus automation and upgrade a vital system on the road to CIBER2 completion.

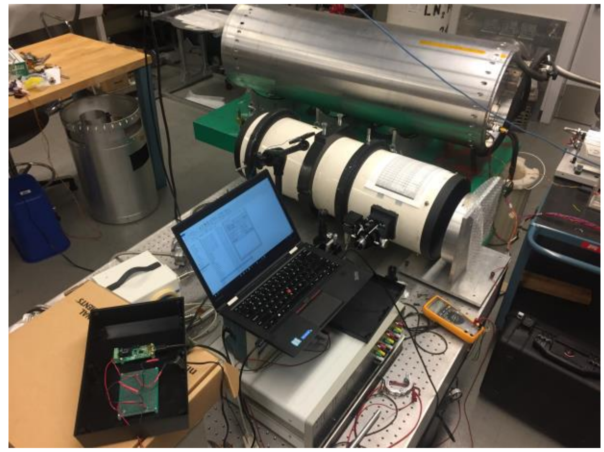

Figure 6: *Program and System Setup*

References:

- Bock, Jamie. "THE COSMIC INFRARED BACKGROUND EXPERIMENT (CIBER): THE WIDE-FIELD IMAGERS." CIBER Instrument Special Issue ApJS (2012): 1, 7-8. Web.

- Zemcov, M. "THE COSMIC INFRARED BACKGROUND EXPERIMENT (CIBER): A SOUNDING ROCKET PAYLOAD TO STUDY THE NEAR INFRARED EXTRAGALACTIC BACKGROUND LIGHT." CIBER Instrument Special Issue ApJS (2011): 14. Web.

- "WELCOME TO MOONLITE TELESCOPE ACCESSORIES..." *MoonLite Telescope Accessories*. N.p., n.d. Web. 10 July 2017.

- "1 CHANNEL USB POWERED RELAY MODULE." NUMATO LAB DOCUMENTATION PORTAL, NUMATO SYSTEMS, 2016, DOCS.NUMATO.COM/DOC/1-CHANNEL-USB-POWERED-RELAY-MODULE

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