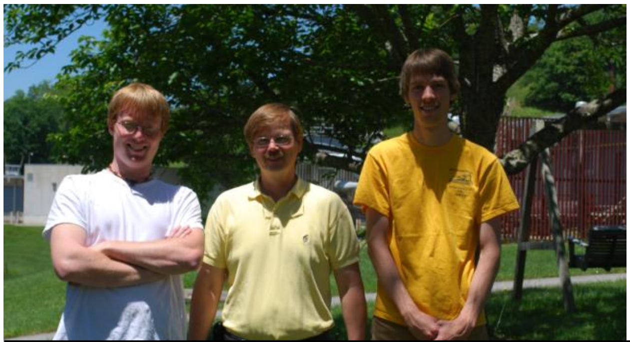
2009

PARI Summer Undergraduate Internships

Reports by 2009 PARI Interns are presented here.



NC Space Grant and Cline Interns with Dr. Castelaz (c)

NC Space Grant Intern working on software for DIRV

PARI Intern working on solar panel controls

NC Space Grant Intern showing PARI staff LabView telescope control software

NC Space Grant/PARSEC Intern working on DIRV correlator

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J. DONALD CLINE SUMMER INTERN REPORT

NC Space Grant/Cline Astronomy Scholarship, Steve Harenberg, UNC Chapel Hill

As recipient of the J. Donald Cline Astronomy Scholarship, I was given a great opportunity to spend this summer working at the Pisgah Astronomical Research Institute as an undergraduate intern. I spent this time using the multitude of resources available to increase my knowledge and interest in science as well as doing meaningful work that will benefit PARI. Before my summer internship began, I met with Mr. Don Cline, and Dr. Mike Castelaz to discuss the goals for my 10-week stay.

Summer 2009 Goals

The original intention was to work on four main projects:

Project 1) **Solar Energy Project**

- Find ideal solar panel tilt angles.
- Analyze measurements from solar panel tilt angle experiments.
- Complete installation and wiring of the panels at site two, the west optical telescope building.

Project 2) **26-m radio telescope control testing**

- Test and take measurements of the East 26-m telescope encoder communication.
- Test and take measurements of the West 26-m telescope encoder communication.

Project 3) **Science Education – PARI's high school programs**

- Participate as a mentor in the PARI Space Science Lab (SSL)
- Participate as a mentor in the Duke TIP Summer Field Study in Astronomy, Physics, and Astrobiology (TIP).

Project 4) **APDA citizen science project**

- Learn about the Astronomical Photographic Data Archive (APDA) and the Stellar Classification Online Public Exploration (SCOPE) project.
- Scan plates for SCOPE and load them into the database.

- Create a manual documenting the process.

Note that Project 2 could not be carried out since the encoders for the 26-m telescopes were not up and running during my attendance.

Solar Energy Project

The first project I endeavored while at PARI was the Solar Energy Project. This was the most intensive project that I worked on during my stay and took up the most amount of time.

We first created a mathematical model which could predict optimal solar panel tilt angles based off latitude, east/west orientation, and the declination of the sun. We then took data by testing different tilt angles from the solar panels that were already installed on the pump-house building. Lastly, with the help of Lamar Owen, we completed the wiring of the solar panels at the west optical telescope building. A detailed description of this project is written in another article.

Science Education – PARI's high school programs

Throughout my stay I was able to get a lot of experience working with high school students during the three separate camps that were hosted at PARI. There were two five-day Space Science Lab (SSL) camps and a two-week Duke TIP camp. The prior was for underrepresented high school students in local western North Carolina, while the latter was for academically gifted students from all over the nation.

During the SSL, students were each able to build their own telescopes from predesigned kits and then use their telescopes to observe the moon. Furthermore, students were able to build a camera mount which allowed them to attach a digital camera to their telescope for astrophotography. I worked with the students while they were assembling their telescopes, assisted them during their nighttime observations of the moon, and answered any questions they had. A few nights we also set up an 8-inch Cassegrain reflector telescope, which we used to let the students look at anything they were interested seeing; most notably, Jupiter with its Galilean moons, and the Globular Cluster M13.

Figure 1 – Here I am working with a Duke TIP student, Joe Cariz, scanning a photographic plate.

During the Duke TIP camp, the students decided on an astronomical topic that interested them and split into groups of three to conduct research. I assisted them while they were working on their research to give advice and help them when a problem arose. I was able to help some groups make charts/graphs, and even assisted one group in making an animation of galactic rotation using the math program Maple. I also ran the Astronomical Photographic Plate Data Archive at this time and was able to help many of the groups locate and scan plates that they were able to use in their research.

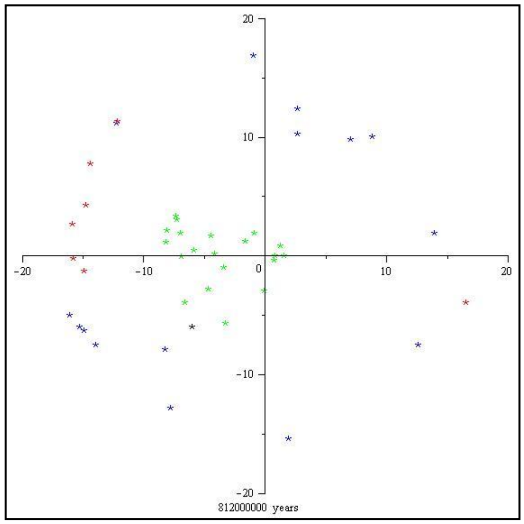

Figure 2 – A picture of the animation which showed the galactic rotation.

Throughout their stay, the students had many events which were taking place. They were required to give a presentation on a recent astrobiology topic, give a final research presentation, use the Smiley radio telescope, and use the west optical telescope. In order to coordinate these events, we created online signup sheets that students could visit on their laptops and grab any slot they wanted. This allowed a simple and accessible way to keep track of the multitude of events that were happening. Moreover, I acted as a moderator during their presentations by introducing each group and keeping track of the order in which they were to present.

Initially, working with the camps was something that I was a little apprehensive of, but I soon found that I thoroughly enjoyed working with the students and was grateful that I could be a positive impact on their stay at PARI. I hope to be able to keep in touch with a lot of them.

APDA citizen science project

PARI is becoming one of the national archives for astronomical photographic plates and currently houses around 50,000 plates. Astronomical data was stored on photographic plates for around 130 years ending in the 1980s. The archive at PARI contains plates dating over 100 years old. These plates are of extreme importance because they are essentially a time machine into the past. Astronomical events happen over long periods of time, so these plates contain invaluable data that allows astronomers to see how objects have changed and evolved over time. It is clear why having a safe and monitored environment for these plates is imperative. That is

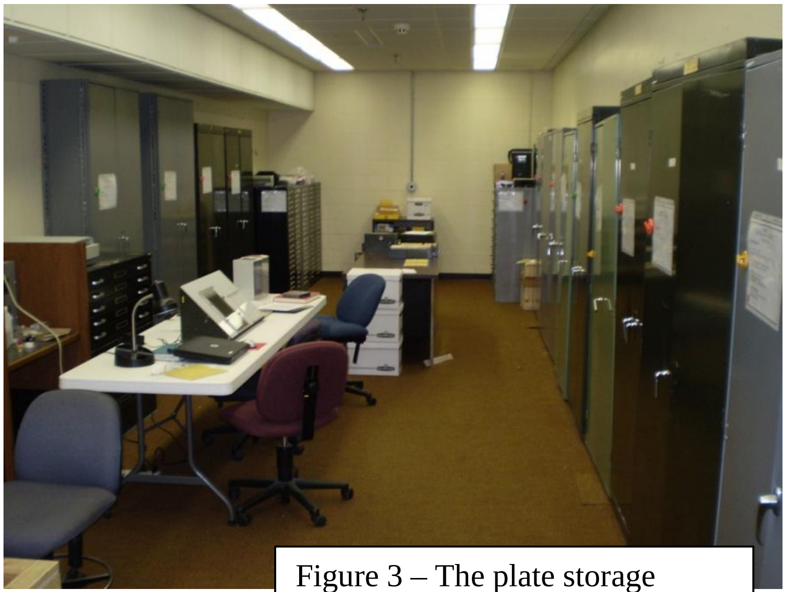

Figure 3 – The plate storage

where APDA comes in. The Astronomical Photographic Data Archive is a safe haven for the plates, providing a relatively dust-free storage, protection from sunlight, and a climate-controlled environment.

The ultimate goal of APDA is to digitize the plates so that they will be available online for the astronomical community, as well as in a more convenient format that requires less maintenance. To realize this goal, PARI already has 120 TB of storage available, as well as a high precision scanner called Gamma II, which was donated by NASA. Although they weren't running Gamma II during my internship, there are plans in the near future to use it in operation.

One outcome of plate digitization would be the SCOPE project. SCOPE stands for Stellar Classification Online Public Exploration. The aim of SCOPE is to allow anyone who is interested to log in, take a tutorial on how to classify spectra, and then begin to classify countless stars that have never been classified before. When astronomers took images they were only looking at a few different stars, but each plate can have hundreds. The amount of data that would be available by classifying and identifying many stars on each plate would be astonishing and a great asset to the astronomical community.

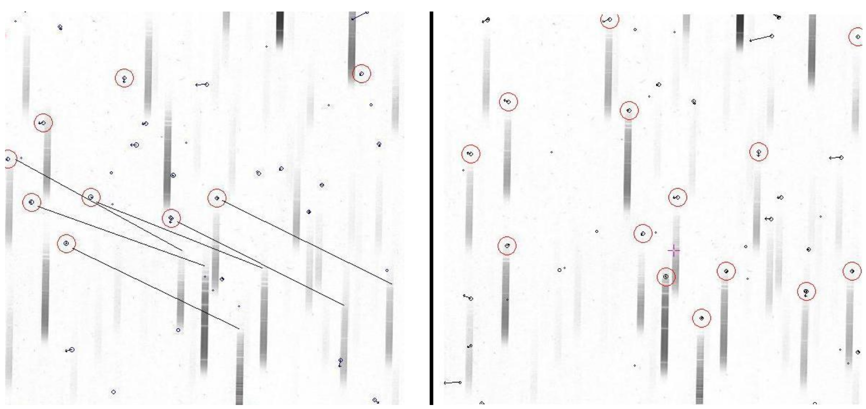

Figure 4 – An example of using Aladin to identify stars. The figure shows how the labels must be shifted due to the age of

Another outcome of plate digitization would be to allow astronomy classes to use the plates in lab classes. The students would be able to access many spectra and get practice identifying and classifying stars and spectral lines. This would be very beneficial, since the study of stars' spectra is a fundamental and integral part of astronomy. In fact, most of what we know in astronomy is solely because of the study of spectra.

During my stay, Thurburn Barker, a volunteer at PARI and director of APDA, taught me about the plate center and how to do many things with the plates. He showed me how to scan them, identify the stars using Aladin, and upload them online so that the public can access them. Using Aladin to identify the stars on each plate was the most difficult process involved. It was tedious and sometimes very tricky. Each plate is labeled with the right ascension and declination (coordinates) that the center of the plate is located at, and they each span about 5˚ fields. However, the plates are very old and therefore the right ascensions and declinations are very old. The coordinates of a star change gradually due to the precession of the earth's axis as well as the proper motion of the star. So, plugging in the given coordinates into Aladin will not produce meaningful identifications. One must calibrate the identifications generated by Aladin to compensate for the change in coordinates that have occurred over the years. This is done by looking to see which identifications should go with which stars based on the spectra, matching them, and shifting everything a certain way. Like a puzzle, sometimes you can see the solution right away – and other times you can't.

After having been mentored and instructed by Thurburn, I began to work with the plates independently, ultimately calibrating and uploading over 20 plates onto the scope website. I also wrote a 13-page manual describing how to scan, calibrate using Aladin, and upload the plates online. I hope that the manual will be a good guide and reference for future volunteers and interns that work in the plate center. Working in APDA allowed me to learn a lot about the spectrum of stars, as well as the different classifications. After going through as many spectra as I did, I can now recognize all the different types of stars by their spectra. I also consider myself fortunate to have observed some really interesting historical data, something not many people have the privilege of being around. Additionally, I was able to take part in the monumental movement of preserving these plates.

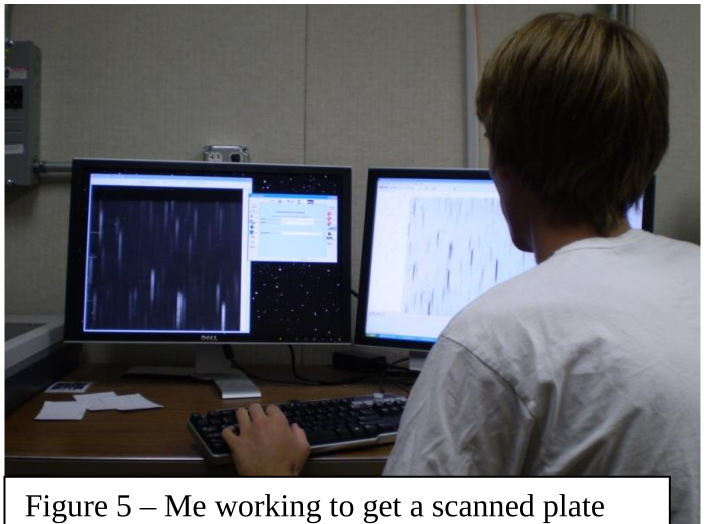

Figure 5 – Me working to get a scanned plate

Final Week at PARI

In my final week at PARI I was able to shadow Ben Goldsmith and help him with his work. Being the site engineer, Ben does just about a little of everything and I feel very fortunate to have had the opportunity to help out. He showed me how to operate the bucket truck and let me set it up and shut it down whenever we used it. I

Figure 6 – Me on the West 26 meter

was also able to take a ride in the bucket up to about 70 feet, which was a lot of fun and maybe a little scary. In addition, we reset the weather station on the optical ridge since it gets knocked out rather frequently by EMPs. Lastly, I was able to assist while tests were being run on the 26 meter telescopes. I had a blast during my last week at PARI and I am really grateful for the experience.

Conclusion

To conclude, being able to work at PARI this summer was an amazing opportunity that I am very grateful for. I was able to work with so many nice people and learn some really neat things. I feel that I had a well-rounded internship this summer; being able to work on many different projects. Wiring was something I had never done before, and being able to learn first-hand from Lamar was a great experience for me. With the solar panels, it was exciting to use things I learned in college to create a mathematical model that we were able to validate using data we collected. Working with the kids and being somewhat of a mentor was something that I enjoyed doing much more than I thought I would, and I am glad I was able to be a positive part of their time at PARI. Finally, being able to work on such a monumental project as APDA was something I am glad I could partake in. This is the only summer job where I have enjoyed going into work and wondered: *What interesting things will I be doing next?* I truly believe that the experience I gained this summer will be a great stepping stone for my further studies and future career in the sciences.

PARI INTERNS PROJECT REPORTS

NC Space Grant PARI Internship, 2009 Summer Report, Joseph Peters

Executive Summary

This report details the work I did as the North Carolina Space Grant summer intern for Pisgah Astronomical Research Institute during the summer of 2009. At the beginning of the summer, I was given a set of goals to accomplish during my internship. The following sections will define the goals as delivered to me, the process of accomplishing these goals, and the final results of my work. I am grateful for the knowledge I have gained through this opportunity, and for the experience of working in such a unique environment.

Expected Goals

The official position of my internship was a focus on astronomical data storage with the Astronomical Photographic Data Archive (APDA). Since I was the only recipient of a Space Grant internship for the summer of 2009, the actual workload was not solely focused on working with APDA. From the beginning of my internship to the end, the primary area of my work dealt with setting up PARI's 26 meter radio telescopes. In the first week Dr. Castelaz and I went over a list of goals I was to accomplish over the summer. The schedule is posted below:

- **Goals:**
  - Radio Telescope encoder development and tests
  - Develop the Radio Telescopes pointing models
  - Double the APDA SCOPE database
- **Week 1:**
  - Orientation – your office, living area, safety at PARI
  - Introduction to radio astronomy: using the PARI 4.6 radio telescope
  - Learning about the 26-m radio telescopes: motion and measuring position using encoders
  - Control of the telescopes using LabView
- **Week 2:**
  - Begin building 26-m radio telescope new encoder enclosures
  - Test new encoder enclosures

- **Week 3:**
  - Install new encoder enclosures
  - Test installation of enclosures using telescope software and LabView software
- **Week 4:**
  - Pointing models for 26-m radio telescopes
- **Week 5:**
  - Finish 26-m radio telescope pointing models
- **Week 6:**
  - LabView development for Dedicated Interferometer for Rapid Variability correlator – combining with the telescope control
- **Week 7:**
  - Begin on APDA project and learn about the SCOPE database
  - Scan plates for SCOPE and load into the database
- **Week 8:**
  - Finish plate scanning
  - Prepare a paper summarizing your summer internship

Many of these goals were accomplished, though several were not. I feel confident that I was able to accomplish the most important goals and all that were possible in the short time I had at PARI. The details of my work are outlined in the following sections.

Digital Encoder Communications

Summary

PARI's largest telescopes are the two, 26 meter radio telescopes which are cleverly called 26 West and 26 East. The most important project I was a part of this summer was a permanent installation of fiber communications between these telescopes' encoders and the computers which control the telescopes. There are two 27-bit digital encoders for each telescope, one for each axis of rotation. The lower axis is called the X-axis or Major. This axis rotates in the

East/West plane. The upper axis is called the Y-axis or Minor. This axis rotates in the North/South plane. Due to the constant threat of lightning strikes in this area, it is necessary to have fiber communications running from the encoders to the computers to limit the possible paths a current surge can travel down.

Weatherproofing

Weatherproofing is an important consideration, since the encoders are exposed to the environment, and are comprised of electrical systems. For the encoder interfaces, we used weatherproof boxes rated to NEMA-4. This means the boxes are weatherproof for any orientation. This is especially important on the Y-axis since the entire upper tier of the telescope rotates with the X-axis. The connectors which we ran thru the wall of the boxes needed to be sealed as well. To accomplish this we used amalgamating tape and silicone to ensure no leaks in the parts of the box we compromised. The circuit breaker boxes we had on hand were only rated to NEMA-3. This means the boxes are weatherproof only when installed and kept in a vertical position. To deal with the rotating Y-axis, we placed these circuit breakers in plastic, NEMA-4 enclosures for the upper axes.

Dry Air

In addition to the weatherproof enclosures, we also ran dry air into the encoder interface boxes. The dry air system was already installed in order to regulate the air inside the DIRV feed-boxes, so it was a simple matter to splice the existing lines to our boxes. The existing dry air hoses were 3/4", we needed to run 1/4" to our boxes. At each axis we cut the 3/4" line and inserted a T-junction with a 1/4" barb which we were able to run hose from. For safety and convenience, we connected the line to the box using a half-turn valve. This way, anyone needing to service the encoder or encoder interfaces will not have to worry about the system being over-pressurized when they open the lid. Inside the boxes we installed air flow regulators so that each box would be able to maintain its own pressure, independent of the pressure at DIRV. To allow the air inside the box to flow, it was important to make sure the system has a way for air to escape. Instead of drilling another hole in the box to allow the air to escape to the environment, we left the exit nozzle of the air flow regulator open to the box environment, and did the same for the tubing which ran to the encoder itself. The box which contains the actual encoder is already a leaky system and we felt enough air would escape from this box to ensure continuous air flow thru the entire system.

Mounting

Mounting both the circuit breaker boxes and the encoder interface boxes to the structures of the radio telescopes presented its own unique challenges. The frame of these massive radio telescopes is solid steel and we had no desire to drill thru it if it could be avoided. Our goal was to find places at each axis we could mount to with pre-existing holes. After much investigation, it was determined that the floor grating of the encoder work decks would be the best surface to mount our encoder interface boxes to. In order to do this, we cut two sections of metal rails, which we attached to the base of the encoder interface enclosures with 3/8" holes extended beyond the sides of the box. For the bottom part of the grates, we cut sections of DIN rail which would be able to fit through the grating, but would catch when rotated 90 degrees. We then cut 3/8" threaded pipe into sections approximately 4" long which would be long enough to fit through the grating, the metal rails, and short sections of DIN rail. Using a combination of washers and nuts we completed the system. The mount is permanently attached to the boxes and in order to remove the box from the telescopes, a user simply loosens the nuts at the top, and then the box mounts can be slid between the gratings. This mounting system relies on friction to keep the boxes in place, so it is important to keep the nuts as tight as possible. A similar setup was used for the circuit breaker boxes on the Y-axes, the only difference being that we didn't need to attach metal rails to the bottom of the box, since there were plastic flanges sticking out the sides already. The circuit breaker boxes on the X-axes couldn't use this type of system since the boxes needed to be mounted vertically. Since each telescope has a different layout on their X-axes, it was necessary to come up with different mounts for each. Both make use of cut sections of U-shaped rail which acts as hooks. By bolting these rails to the boxes we were able to hook the rail over a section of the structure, thereby using gravity to keep the boxes in place.

Labeling

Since multiple people might be working on these encoder systems, it was important to label each part and component to avoid confusion. The four systems are very similar to each other and use many of the same parts. With this in mind, I developed a labeling scheme which would, for each part, identify that part's telescope, axis, and location. The scheme is structured as: telescope (W/E)/axis (X/Y)/location (N/L)/part, where N is the ND-280 area and L is the LCU. So for example, the RX fiber cable for the X-axis located at the LCU on 26 West would be labeled as WXL RX Fiber. The Fost CDR for East's Y_axis inside the encoder interface box would be labeled as EYN Fost CDR.

Power

The power for the encoder interfaces is spliced from the 3 phase 208 power cable which runs through flex-conduit to the DIRV feed. We needed to have a power cut-off at each encoder to allow for maintenance, so we installed a circuit breaker at each location. The flex conduit is run into the weatherproof breaker box enclosures, where it is cut. The ground wire (green) is attached to the ground bus on the circuit breaker, where grounds are then ran to the lightning arrester and both outputs. The neutral wire (white) is attached to the neutral bus where neutral wires are then run to both outputs but not the lightning arrester. The red and blue wires are connected to their counterparts, which continue up to the feed box with wire nuts connecting the two lines. The black, single phase wire is connected to the top of the circuit breaker and to the black wire which continues to the feed box. A black wire is then connected to the bottom of the circuit breaker, and is then run to the lightning arrester and out to the encoder interface box.

Shielding

Since the telescopes are trying to pick up radio wave signals, it is important to shield all components which might emit electromagnetic radiation. To do this we shielded the encoder interface boxes with copper mesh. It is possible that further steps may need to be taken in the boxes such as an absorbent silicone coating. This method has been mentioned several times but I was never given the go-ahead for it. The power was another concern. To deal with this we used metal enclosures for all circuit breakers and ran the power wires through metal conduit.

Fiber and Communications

The fiber communications running to the encoders have multiple lines, more than was necessary. For convenience, we connected wires three and four to the Fost-CDRs. At the encoders, line 4 is considered RX and line 3 is TX. This is opposite at the LCU where line 3 is RX and 4 is TX.

In order for the computer at the LCU and the ND-280 to communicate, it is important for each to have the same communications settings. They both should be set to the following:

- Baud Rate: 115200
- Data Bits: 7
- Parity: Even
- Flow Control: None
- Output Tail: 0

- Stop Bits: 2

These settings are absolutely necessary to get any intelligible data from the encoders. When troubleshooting the encoder it is recommended to start with these values since they have given us problems in the past.

Troubleshooting

Hopefully nothing will go wrong with the system, but...

Dry Air

If dry air is not flowing through the encoder interface box, first check the dry air system at the base of the telescope with Thad. If the base system is functioning correctly, check the half-turn valve between the box and the main dry air line. This valve should have the handle in-line with the hose for open flow. Lastly check the flow regulator inside the encoder interface box. To do this, pull the yellow knob out, then rotate it to adjust the air flow. If all of these connections are open and dry air is still not working, check all hose lengths for leaks and kinks.

Power

Before working with any of the electrical systems for the encoders it is important to kill the power at the circuit breaker in the LCU and test the line with a voltage meter. If power is not working in the encoder interface box, make sure all circuit breakers are in the correct position. If power is still not working, check for loose wires at the circuit breaker, in the box's outlet, and at the LCU end.

Communications

If communications are down, even though all components have power, first check that the communications settings for the ND-280 and the DFM software are as shown above. If they are correct and the problem persists, make sure it is not a software issue by clicking on the Telnet icon on the desktop of the computer at the LCU. When the session is open hold down

CTRL + B. If an encoder value such as 6.0485 comes on the screen, then the problem is related to the DFM software. If no number is shown on the screen, check the fiber connections to make sure each line is in the correct port at both the LCU and ND-280 Fost CDRs. Also make sure you can see red light coming out of each RX cable (Important Note: Do not look directly into the light of the fiber connector! Shine it against non-mirrored surface!) and you can see no light coming out of each TX cable. If TX is emitting light, your connections are backwards. If RX is not emitting light, then either your connections are backwards or a cable is unplugged.

Encoder Communications Summary

As of the writing of this report, the fiber communications for 26 East and West are completely installed and functioning correctly. Communications between the encoder and LCU have been successfully tested and we are now capable of controlling the telescope movements from the computer. The system is also fully labeled and correctly configured.

There is one major issue still needing to be resolved which is the responsibility of DFM engineering. When tracking is turned off and coordinates are input to the computer in right ascension and declination, the telescope is never able to achieve its final position. This is due to the fine movement rate of the telescope being less than the rotational velocity of the earth. DFM is aware of this problem and has documented it in their user manual for the controls. It is important to resolve this problem if we are going to be able to control the telescope from the OCU computer, since all coordinates sent from that computer are in RA and DEC. The continued tracking itself is not the only problem, since even if a user sends the stop command from the OCU, the telescope keeps moving with no indication. This can be very hazardous since a user will be under the assumption that all motion has stopped with no contrary indications..

One solution to this problem, which should be mentioned to DFM, is the possibility of converting RA and DEC coordinates into X and Y while tracking is disabled. Since the continued motion does not occur with X/Y coordinates, this will allow the telescope to stop at the input position without continued movement.

LabVIEW Telescope Controls

Now that the encoders are interfaced with the DFM computer system, a user can use the DFM software to point the telescopes at any object of interest in the sky. One of the first things PARI asked me to do was implement a program using LabVIEW, which could communicate with the DFM computers and send the commands from a desktop computer in the control room to the DFM computers. The purpose of this program was to give the 26 meter radio telescope users more functionality. Using the commands DFM has supplied us with, I was able to create the desired program.

DFM Commands

The computers at the LCU of the 26 meter radio telescopes are able to receive certain commands over a TCP connection. DFM supplied us with eighteen different commands to use:

- **Command 1 - Update**: Sets the clocks and will initialize coordinates to the zenith if the system is not yet updated. Initializes date and time if system is initialized.
- **Command 2 - Zenith**: Initializes the major and minor position encoders.
- **Command 3 - Slew**: Sets slew position.
- **Command 4 - Offset**: Sets offset motions in arc seconds from the telescope mean coordinates in the display epoch.
- **Command 5 - Object**: Slew to library of objects.
- **Command 6 - T-move**: Procedure slews to an object previously stored with the mark command.
- **Command 7 - Zenith**: Slews the telescope to the zenith.
- **Command 8 - Go**: Initiates motion commands.
- **Command 9 - Stop**: Cancels automatic motion commands.
- **Command 10 - Track**: Changes the track rate for RA and DEC.
- **Command 11 - Guide**: Changes guide rate for RA and DEC .
- **Command 12 - Set**: Changes the set rate for RA and DEC .
- ***Command 15 Spare***: *Spare command slot.*
- **Command 14 - RateCor**: Turn on track rate correction function.

- ***Command 15 Spare***: *Spare command slot.*
- **Command 16 - DoEpoch**: Sets the display epoch.
- **Command 17 - Mark**: Stores RA, DEC, and epoch into the mark table at indicated position.
- **Command 18 - Coefficients**: Change telescope and pointing model parameters from excom.
- **Command 25 - Coords**: Returns telescope coordinates, time and date to the excom.
- **Command 26 - Stat**: Sends telescope stats back to the excom.

Of these eighteen commands, we only use five of them in our LabVIEW code. The five we use are Slew, Go, Stop, Coords, and Stat.

Documentation

Most users will not need to access the control program's code in order to fully use it. There may be a time when a user needs to increase the functionality of the program by making changes to the code. In order to make this process as easy as possible, the code has been documented in LabVIEW. There are a few notes in the code itself to explain what each broad block of code does. Also, each sub-vi has a brief summary of its functionality. These summaries can be found from the top menu in LabVIEW by clicking on File and selecting VI Properties, in this window there is a Category drop down field, select Documentation from this drop down menu. There will be a text document showing the VI's functionality, inputs, and outputs.

Functionality

To access the LabVIEW control program, you must first log into the control computer. The program is on this computer's hard drive in the directory C:/Labview/Control_26m. Once the program is open, click on the white arrow in the upper left corner of the screen. If the program is running correctly, the arrow should turn black. To stop this program, click on the red stop-sign shaped button next to this arrow.

The control program consists of three different types of function: Data display, coordinate input, and error checking. Each of these functions has different interactions with the user as well as their own block of "code" in the program.

Data Display

We needed for any user working with the 26 meter radio telescopes to be able to access as much information as possible about the current status of the telescopes. The necessary data included coordinate positions, system status, and time. Using the DFM commands 25 and 26 (Coords and Stat), we were able to retrieve the following information for the user:

- Boolean status indicators
  - System Initialized
  - Brakes on
  - Track on
  - Slew enabled
  - Lube pumps on
  - Approaching Limit
  - Final Limit Reached
  - Slewing
  - Target out of range
  - Min + hand paddle button pushed
  - Min - hand paddle button pushed
  - Maj + hand paddle button pushed
  - Maj - hand paddle button pushed
- Telescope's Current Coordinates
  - Hour Angle
  - Right Ascension
  - Declination
- Current Time
  - Epoch
  - Sidereal Time
  - Universal Time
  - Year

The program displays all of the boolean status information as indicator lights, on for true and off for false. The current RA and DEC and time information for each telescope are displayed in fields.

Coordinate Input

A user is able to input coordinates for the telescope to point to. These coordinates can be in the form of right ascension/declination, X/Y, or by selecting an object from a drop down list. There is a tabbed area on the control panel which a user can click on to select which coordinate system they will use. All of the coordinates are converted to RA/DEC before being sent to the DFM computer since these are the only coordinates we are able to communicate with.

There is an offset option with the program as well. The offset would be used if the user wished to direct the object's data to a feed other than the DIRV feed, such as a Furman's Pulsar feed. The coordinate inputs for the offset are in X/Y. To use, input the X/Y offsets corresponding to the feed you wish to use and click the offset enable button. This button latches so that it is green when offsets are enabled and red when they are not enabled.

The user also has the option of which telescope they wish to control. There is a drop down field in the top left corner of the program window which has the option of East, West, or Sync. It is important to note that the program only controls the selected telescope. If a user clicks the stop button, and only East or West is selected, then only the one telescope will be stopped. In an emergency situation, make sure Sync is selected before clicking stop.

Error Checking

The program is more than just an interface between a user and the DFM computer. The program also runs background checks on proper function of the telescopes. Every time a coordinate is input, the program checks to make sure the object is within range. If an object is out of range, the range indicator turns red and the message "target is out of range" is shown in the Error Message field. Also, if the selected coordinates are not in range, the program will not do anything if a user presses the Go button. Also, the program stops the selected telescope if the target moves out of range. The program currently has more restricted limits than the DFM software, with angles greater than sixty degrees considered out of range.

Another continuously running check is the encoder status check. This section of code constantly compares encoder readings to make sure the encoders are functioning correctly. If there is an encoder error, the encoder status indicator turns red and a message is displayed in the Error Message field telling which encoder is malfunctioning. This block of code also sends an all stop signal to the telescopes currently selected if there is an encoder problem.

LabVIEW Controls Summary

The control program is complete as of the writing of this report. Each command has been tested with 26 East and worked as expected. The interfaced control program also runs as expected with no errors. It is expected that the desired functionality of the program will expand in the future. When this is the case, it will be reasonably simple for someone familiar with LabVIEW to make the necessary changes to the program.

Additional Projects

While working at PARI there were always additional projects which needed to be done. These would range from working with the students of TIP and Space Science Lab to full scale projects which could take a day or more.

Working with students was surprisingly one of my favorite parts of my summer internship. In both work and play, the summer students at PARI showed a remarkable degree of imagination and inquisitiveness. Although I never had to deal with the students in a professional sense, there were many instances where I would spend extended amounts of time with them as a friend and as an informal educator.

One of the biggest side projects I worked on this summer was the construction of a telescope dome. The dome was donated to PARI a couple of years ago and has remained disassembled for the durations of its time here. The dome parts were very dirty and cluttered with mechanical components which weren't in use anymore. I decided to spend a day assembling and cleaning the dome so it could be used with one of PARI's optical telescopes.

The dome is currently set up in the parking lot behind building one and houses one of PARI's 8 inch optical telescopes.

Conclusion

My summer internship at PARI has been busy, exciting, and fulfilling. It has been a pleasure to work in such a unique environment with so many wonderful people. I would like to thank Ben Goldsmith, Dr. Michael Castelaz, Lamar Owen, and Donnie Curto for their help with my projects and all they have taught me. I look forward to working with everyone again when I am able to come back as a volunteer.

Solar Energy at PARI, Leigha Dickens, PARSEC Intern and Steve Harenberg, Cline Scholar

This summer PARI was in the process of installing photovoltaic arrays at four sites on the optical ridge. At the time of this writing, site one attached to the pump house, and site two attached to the west optical telescope building were complete, although telemetry remains to be developed and installed for detailed system monitoring. The photovoltaics installed in sites one and two are rated to produce 5 amps, but the performance and power output of the overall system varies due to many factors. The number of panels and size of the battery bank is fixed by budgetary constraints, as is the east-west orientation of the buildings on which the panels are attached. Panels at sites one and two are built on adjustable mounts; the most accessible way to maximize the power output of these arrays is to adjust the panels' angle with respect to the horizontal throughout the year, as intensity falling perpendicular to the panel's surface will create the most current.

This summer we have measured the east-west orientation of these buildings, and applied a math model based on the spherical geometry of the sun's movement across the sky to determine the optimal tilt angles for the attached panels at various times of the year, and compared them to results obtained in a similar way by Mike Castelaz, who assumed due south orientation of panels. We also took several measurements of the current coming off of panels at site one at various times of day, tilt angles, and weather conditions. Toward the end of the summer we completed the wiring, activation, and testing of the system at site two. Leigha also attempted to develop a computer program that could begin communicating with the inverter at site one and collecting data, but was unsuccessful.

Model

One of our goals was to create a mathematical model that could help us find the optimal tilt angle for the solar panels at varying times of the year. Since the sun's path in the sky changes throughout the year, changing the tilt angle of the panels, based on declination, can increase the efficiency and output. An established convention is to have solar panels facing due south, since the sun's path is most favorable for south facing panels. Multiple solar panel sites are being built at PARI and not all of them are/will be south facing, so another thing we wanted to find from our model was how the optimal tilt angles were affected due to different orientations of the panels' faces.

To build our model we used the dot product of two vectors (Equations 1 and 2); one representing the direction perpendicular to the face of the solar panel, and one that spans from the ground to the sun's position in the sky. These vectors were obtained using spherical geometry. Let θ= the sun's altitude, φ= the sun's azimuth, n= the direction the solar panel is facing (180° is south), and β= the tilt of the face of the solar panel, with 0° being parallel to the ground.

$$Vpanel = -\cos(n)*\sin(\beta)*\sin(n)\,\mathbf{x} + \sin(n)*\sin(\beta)*\cos(\beta)\,\mathbf{y} \quad (1)$$

$$Vsun = -\cos(\varphi)*\cos(\theta)\,\mathbf{x} + \sin(\varphi)*\cos(\theta)*\sin(\theta)\,\mathbf{y} \quad (2)$$

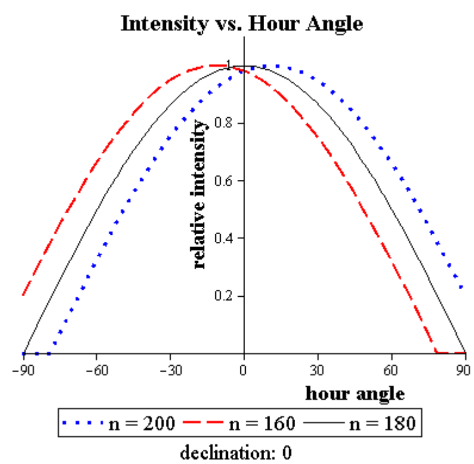

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Figure 2: Plots of solar intensity verses hour angle for panel orientations of due south (180°), and 20° east or west of south. Intensity is normalized

Since they are unit vectors, taking the dot product of these two vectors will give an answer between 0 and 1. If the value is 1 then the sun's rays and the panel's face are perpendicular. Integrating the dot product of these two vectors from sunrise to sunset will give us a relative daily intensity (Equation 3):

$$\int(\cos(\varphi)*\cos(\theta)*\cos(n)*\sin(\beta) + \sin(n)*\sin(\beta)*\sin(\varphi)*\cos(\theta) + \cos(\beta)*\sin(\theta))\,dh \quad (3)$$

Note that φ and θ are functions of h

By comparing the relative daily intensities produced by different solar panel tilt angles we can find which tilt angle is the best for a given declination, latitude and orientation. To find the best tilt angle we wanted the maximum value of the integral. To find this we took the derivative with respect to β, set it equal to zero and solved for β. First we found the optimal tilt angle for different times throughout the year at PARI's latitude by setting the orientation to due south, and spreading the declinations from summer to winter. We also looked at how this would change if the solar panels were oriented off from true south. By measuring the shadow cast by building 21 at solar noon, we determined that it faces roughly 11˚ west of south, and by making a line from the equatorial mount of the west optical telescope we determined that building faces roughly 11˚ east of south. Our model reveals that even a 20˚ offset makes very little difference in the optimal tilt angle; an 11˚ change is practically invisible. Although a slight difference in optimal angles can be seen in winter, it is clear that such small differences in east-west orientation do not need special consideration at this latitude.

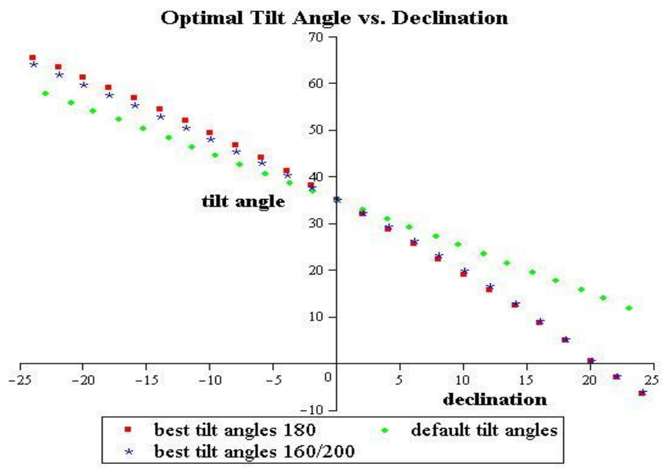


Figure 4: Optimal tilt angles for panel orientation of due south (180˚), 20˚ east or west of south, compared to the industry default of latitude minus declination.

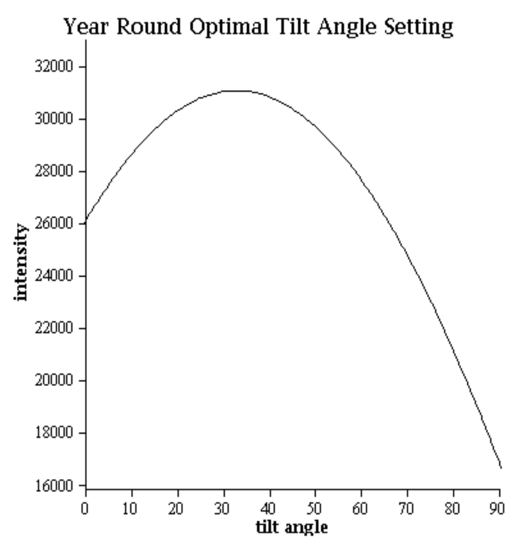


Figure 3:A double sum in Maple allowed us to generate a plot of yearly intensity vs. tilt angle. Yearly intensity peaks around 33˚, a value close to PARI's latitude.

We thought it would be interesting to determine the best tilt angle for a stationary mount. We performed a double sum in Maple, ranging β from 0˚ to 90˚, and subsequently the declination from -23.5˚ to 23.5˚ (winter to summer); this method takes a tilt angle and sums up all the daily relative intensities for the entire year. Whichever tilt angle has the greatest sum will get the most direct sunlight throughout the entire year. The number we got was 33°, and the best tilt angle for a 0° declination is latitude, at PARI, 35˚. Summer has longer days and consequently produces more daily intensity than the winter, so it is logical that a year-round tilt angle would be slightly shifted to favor the summer months.

<u>Measurements</u>

We measured the current produced by panels in site one set at various tilt angles, to determine what difference in power output can by observed when panels are off from optimal in summer. The shallowest possible angle that the panel mounts allow is approximately PARI's latitude minus summer declination, so we were unable to test our calculated optimal angle of -2˚ for a solar declination of 22.5˚ in late June. We compared the current output of four panels set at PARI's latitude, 35˚, and at Castelaz's calculated November setting, 56˚, to the current output of four reference panels left at latitude minus declination. Measurements were taken in full sun and in fog, and at various times daily.

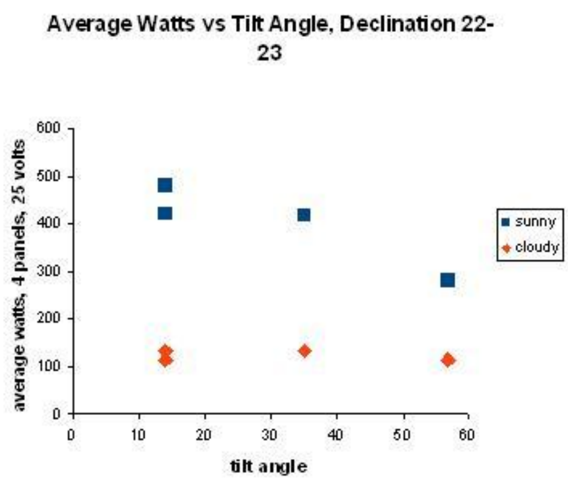


Figure 5:Power output from average measured current, at 25 volts, of 14°, 35°, and 56° tilt angles in full sun and full cloud conditions.

To compare the power output, we totaled the average current coming off of each panel in full sun and in shade, and multiplied each four-panel circuit by 25 volts, the nominal voltage of the batteries in our system. We compared the power from a 35˚ and a 56˚ tilt to the corresponding reference circuit separately for sunny conditions and foggy conditions, as current results from a point source in full sun and from diffuse radiation in fog. As expected, there was little difference in power output as a function of tilt angle in foggy conditions; in sunny conditions our 35˚ and 56˚ test angles produced 84 and 66 percent of the power produced by the reference panels, respectively. From our model we have also calculated the theoretical reductions in solar intensity received by panels that are off from optimal tilt in winter, summer, and fall/spring. Our model agrees with our data when we compare our test angles to our reference angle, indicating our model is a good fit for full sun conditions. It is clear that solar tilt angle matters less in cloudy weather, which predominates at PARI. From measurement and model we have concluded that tilt angles within 20˚ of optimal provide adequate power.

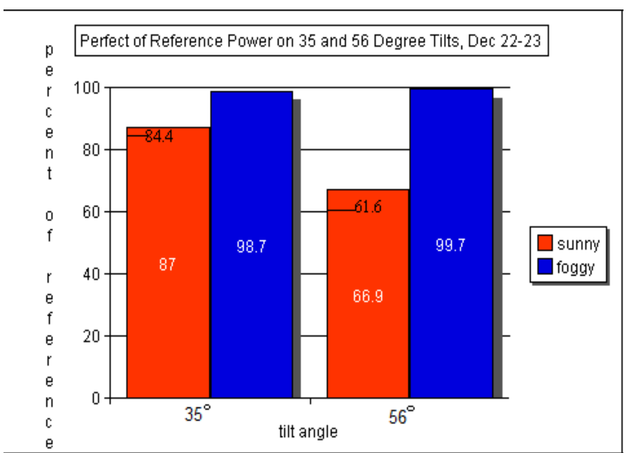
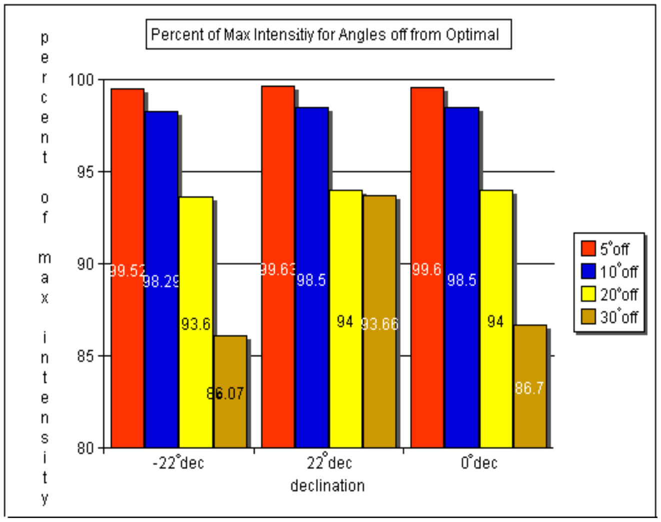


Figure 6: a) Percent of reference angle (14˚) power measured at site one, for 35˚ and 56˚ tilts, in sunny and in foggy conditions. Model predictions are marked in black. b) Calculated percentages of intensity received by panels at optimal tilt angle, that would be received by panels at various degrees off from optimal, in summer, winter, and spring.



Installation of Site Two

During the latter part of the summer we completed the wiring and activation of the photovoltaic system at site two, powering the west optical telescope building. A wire diagram by Leigha is included in Appendix A. An earlier rough power budget, where wattage of each device in the building was measured, indicates that a 1500 watt system, which 12 panels (5 amps) and 8 batteries (25 volts) provide, is theoretically capable of powering the peak value of 870 watts used there. Site two utilizes a Maximum Power Point Charge controller, which tracks the voltage and current coming off of the panels and changes them to the voltage and current which create the most power under current weather conditions and battery state of charge. We verified accuracy of the charge controller by turning on panels one at a time and comparing the charge controller's current reading to the reading of an ammeter connected in series, finding an average percent difference of less than 4% between instruments. MPPT charge controllers can greatly increase the efficiency of a photovoltaic system, and we have preliminary evidence that the capability of the panels at west optical to keep batteries charged is greater than at building 21/22.

Future Direction

Our model assumes full sun conditions, something not particularly common at PARI. A more accurate idea of the best tilt angles could be realized if a way to determine annual or monthly cloud cover were devised. PARI has on-site weather monitoring, but so far only has data from April to June, while the National Solar Radiation Database provides decades of insolation and cloud cover data, but for Asheville. We have attempted to attack this problem experimentally by determining panel responsiveness to tilt angle in summer in various weather conditions. The amount of power lost between our reference angle and our test angles agrees with our model in summer; we would like to come back in December to perform similar tests at winter declinations. We would also like to expand our tests to "partly cloudy" days, or else use our results of sunny and foggy conditions, as well as real weather observations, to determine how best to weight our model for clouds and sun. We have also begun to observe an "edge of cloud effect", whereby the sun catching the edge of a cloud causes a voltage and current spike which often exceeds the 5 amp rating of the panels. Better understanding of this phenomenon would help us understand its significance in the overall power output of the panels.

Additionally, continued monitoring of each site through telemetry that can log information about input and output currents, voltage, load, and battery state of charge, especially a comparison between sites with and without MPPT charge controllers, will help build an understanding of the performance of each system in all weather conditions.

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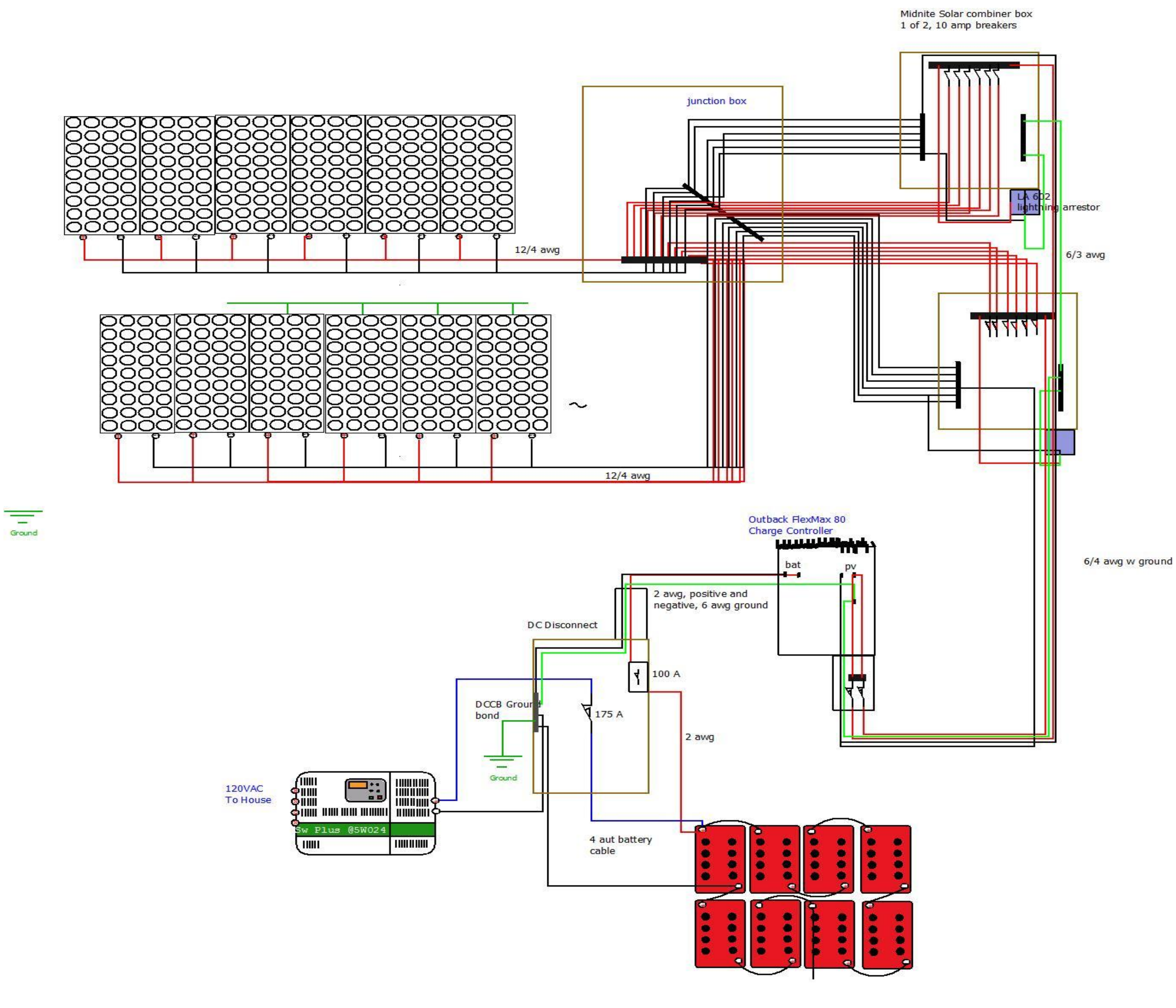
Appendix A, wire diagram of installation at site two, west optical telescope building.



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