Fifth NAIC/NRAO Single-Dish Summer School, 2009
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When I received the email from the NAIC/NRAO asking for applicants for the 2009 Fifth Single-Dish Summer School, I applied with no expectations. After all, why would astronomers want a statistician? The online application was straightforward, except for the required paragraph or two explaining why I wanted to attend the school. I kept it simple, but I did give my DSES affiliation and the DSES website link. As it turned out, the selection committee perused the website, and its contents contributed to my acceptance! The lesson here is to keep your activities current and posted to the website. At this moment, I must thank all DSES members for an organization that encourages each of us to grow and develop our skills in radio science and radio astronomy.

Figure 1: Megan and Ashley.

The Saturday, July 11, 2009, flight from Denver to Atlanta took the same amount of time as the connection from Atlanta to San Juan, Puerto Rico. My friend Ashley (I met her at the January 2009 Union of Radio Science International (URSI) conference in Boulder) met me at the San Juan airport. She and Megan, her office mate - they're both Ph.D. astronomy students at the University of Maryland - were accepted into the school as well. They actually spend a fair amount of time at the Arecibo Observatory as part of their degree program, so I was with very capable guides.

The two-hour drive paralleling the Atlantic Ocean coastline was interesting in that the distance signs read kilometers while the speed limits were in miles per hour. Regardless, we arrived in the city of Arecibo and checked into the Buen Cafe hotel. Ashley insisted we have dinner at the Salitre restaurant. The cuisine was unique and absolutely delicious. I had the red snapper, which melted in my mouth. Oh, and the mojitos, made from pure cane sugar, were divine. Be sure to sit on the patio, as the sunsets over the Atlantic were stunning.

The girls and I decided to make a leisurely drive to the observatory on Sunday morning as registration was from 10 A.M. to 2 P.M. local time (lt). We arrived at noon, and we were sent to the cafeteria parking lot as Ashley had a visiting researcher pass - very nice. The ascent to the Learning Center was tortuous. The incline seemed like it was never less than 45 degrees. The humidity seemed to wring out all my energy. However, with the "Little Engine That Could" in mind, I huffed and puffed my way to the Center, pulling my laptop trolley behind.

I fell into a chair and registered. The coolness and dryness of the air conditioning was a tremendous relief. No sooner had I clipped on my identification badge we were asked if we wanted to join the next tour of the suspended feed platform.

On my feet again, but without my computer trolley, we proceeded once again uphill on what had to be a 60- degree incline. (Ok, I'm exaggerating, but it sure felt like it.) Our group gathered at the base of the catwalk where another totally uphill trek stretched before us. Difficulty with heights notwithstanding, I was not going to deprive myself of a possible once-in-a-lifetime opportunity. I set my jaw and went last. With nearly everyone half my age, I didn't want to slow them up.

Figure 2: On the catwalk headed up.

Although young people often trivialize the word "awesome," I can truly say that this is exactly the right word to describe this tour. To the North was the Atlantic Ocean. The other compass points terminated in two to three thousand-foot mountains whose peaks were below our vantage point. Five hundred feet under our shoes was the expanse of the 1,000 feet of aluminum bowl. Before us was the Gregorian dome and the radio room for the ninety-five-foot yagi mast.

My group was allowed to go everywhere on the suspended feed. Our first stop was the yagi radio room. It was packed with nineteen-inch racks of electronics and it was air conditioned (of course) providing relief for a brief time from the humidity. (By the way, you know someone is from Colorado when they say 25% humidity is uncomfortable. At the observatory I felt like I was swimming with humidity in the nineties.) From the yagi radio room, we walked to the azimuth track. The wheels on the track reminded me of the azimuth trucks at the Greenbank Byrd telescope. Next, we traversed a multitude of very narrow stairways, ramps, and ladders. From the top to the bottom of the suspended structure was at least three stories and no elevators.

To get to the Gregorian dome, we descended a very narrow stair spiraling partway around the azimuth axis. It was a series of stairs to the top side of the feed support. We couldn't go into the dome until the group in front of us was out, so we went to the end of the feed support. There is no protection out there to prevent falling; suffice it to say, I stayed away. The incline to reach the end is quite steep, so it could be used as part of an exercise routine. End-to-end, the feed support allows for a telescope view of ± 20 degrees from the zenith in any direction.

The Gregorian dome was incredible. Once inside, we were right next to the secondary and tertiary reflectors. The reflector geometry is interesting as they allow the energy from the spherical

Figure 3: Azimuth hub with the Gregorian dome below.

primary to come to a focal "point." The cross-section of the secondary reminds me of Darth Vader's helmet. The tertiary reminds me of the bowl of a spoon. The acoustics inside the dome were surprising. The amplified twittering of birds flying between the secondary and the tertiary sometimes made it difficult to hear our guide.

Figure 4: Primary dish, a piece of the secondary at the top, and a piece of tertiary lower right.

Our viewing platform was immediately below a turntable containing a variety of feed horns. The turntable is about eight feet in diameter. We couldn't stand upright even if there were no feed horns, and the open grate was murder on my bare knees. However, the view was worth some discomfort. Our guide had the control room rotate the turntable so we could see all the horns. I remember the 408 MHz horn was about two feet in diameter. There were two about six-inch diameter S-band feed horns immediately adjacent to each other: one for transmitting and one for receiving. The turntable had many other horns as well, one of which I remember had a crossed-dipole antenna. The turntable rotates at slow speed, but has a faster "jiggle" speed to alternately place back and forth first a transmit horn followed by a receive horn.

Back up the vertical ladders we used to reach the viewing platform, we entered the radio room containing the turntable. A plethora of receiving and transmitting equipment rode the turntable

Figure 5: Feed horns on the underside of the turntable.

above each feed horn. It was hard to miss the 408 MHz waveguide dropping from the ceiling of the room. We first encountered this waveguide as we approached the catwalk back on the mountain. The waveguide dove under the catwalk, which carried it to the suspended platform. This waveguide carries up to 2.5 billion watts of transmitted energy.

There was a constant throbbing in the radio room due to the cooling systems. Our guide told us that after sonic enhancement, this was used as the Vega pulses detected by Ellie Arroway in the movie version of Carl Sagan's *Contact*. Does this mean the VLA is so sensitive it can detect cooling cycles in Arecibo? The throb was was periodic: it didn't come in packets of prime numbers (unless you use a packet of size one).

Our tour ended, and while most of us traipsed back down (finally, a down) the catwalk, three decided to try the cable car. The guys riding it told me later that there was no sway from the wind whatsoever. We must have been quite a sight for the tourists on the museum observation deck watching a bobbing bunch of orange and yellow hard hats undulating down the walkway. The reward at the end: air conditioning!

Figure 6: Headed down.

No sooner had we entered the Learning Center than we were directed (down again - wha-hoo!) to the museum lecture hall where we began our schooling in radio astronomy. I refer you to the

lecture schedule at the end of this paper. The entire student body, including Research Experience for Undergraduate (REU) students, sat through three hours of lectures. When the lectures were finished, each Summer School student was assigned a mentor for the hands-on projects. I was one of three designated for the OH/IR project. More on this later.

Sunday dinner was tasty and gave us a chance to socialize. However, my mentor, Murray Lewis, rounded up the team before I finished eating and took us to a conference room in the office building next to the control room building. Fortunately, Murray had a car so the down (not so bad) and then up (not so good) didn't aggravate my still-suffering glutes. Once installed in the conference room, we fell to preparing for our observing session while the Coqui frogs serenaded us. The time was 6:30 P.M. lt. We were tasked with finding a calibration source, an OH/IR star, and a Proto-Planetary Nebulae (PPN). The source selection criteria were that they need to be in the beam limits during our two-hour observing session, and they had to be sequenced such that the calibration source needed to be the most westerly object with the others successively east. My two teammates were Ph.D. astronomy students, so this exercise wasn't at all new to themthough I was challenged.

Figure 7: Coqui frog.

Our observing program was using the Arecibo dish (about half the projects used the Arecibo telescope, and the other half used the Greenbank telescope in West Virginia) to study the OH hyperfine resonance levels of two sources and one calibration source at six frequencies, each left and right polarized, with 800 KHz bandwidth, and in MHz: 1,612.2310, 1,665.4018, 1667.3590, 4,660.242, 4,750.656, and 4,765.562. Our calibration source was Quasar B1622+23, and the study sources were OH/IR star B16260+3454, and PPN B18095+2704. We needed to identify the sources by sidereal time, obtain the local time, and convert from 1950 coordinates to the current epoch.

At 9:30 P.M. lt, we packed up our gear and headed up (not too far up) to the control building control room. Promptly at 9:44 P.M. lt, the team at the telescope controls collected their equipment and vacated. Our team began observing exactly on time at 9:45 pm lt. For the next two hours, we positioned the Gregorian dome to first collect dark sky data, switch on the noise diode, dark sky, calibration source, diode, dark sky, OH/IR, etc., then changing feed horn to either the 1.6 GHz or the 5 GHz feed. The time seemed to fly. At 11:45 P.M. lt, we were off the telescope. Team changes at the telescope were as choreographed as any ballet. We avoided the Greenbank control station where another team was working, found an empty room, and debriefed. I finally fell into bed at 1:30 A.M. lt Monday morning. It was intense!

After five hours sleep, I was back in the lecture hall, eager for the day to commence in spite of being bleary-eyed. I attended all the lectures and worked the assignments. I learned a tremendous amount about radio telescopes and radio astronomy. I finished the day by socializing then finally sleeping - I still had to make up for Sunday's loss. Tuesday, the action continued.

Cell phones and digital cameras were required to be off while on the Observatory campus. Hence, it wasn't until I returned to my hotel Monday night that I got the voicemail message telling me I needed to write and fax a letter of commitment on a medical study for which I'm the principal statistician. I attended the first lecture session and then requested help from the observatory staff for help with the fax. The staff was amazing. I can't thank them enough for helping with this problem and all the other situations they ameliorated for all the students. They graciously provided me all the communication resources I needed to write, print, and fax the letter before the Wednesday deadline. The downside is that I missed the latter morning lectures and the group photo.

Figure 8: The 2009 School.

I attended the early afternoon lectures and did the exercises, all a lot of fun. At the afternoon coffee, my mentor told me to get my teammates and meet him in his office at 3 P.M. lt. I checked the lecture schedule for the afternoon and found it was about canned analysis. Clue: my team wasn't going to do canned analysis! As instructed, I informed the boys, finished my break, then, promptly at three, I entered Murray's office. The boys, however, had other obligations. The advantage: I had Dr. Lewis' undivided attention. The disadvantage: it wasted some of his time in that he couldn't do the astronomy contained within the data.

For the next three hours we discussed data analysis methods and techniques. I learned in these three hours what was taking me months to extract from the astronomical literature. Murray said astronomical data reduction was more a mentor-to-student conveyance than a subject in astronomical publications. I'll never be able to thank him enough for his time.

Wednesday morning was for project data analysis. The boys once again were otherwise occupied, so I had another three hours or so of one-on-one radio astronomy data reduction tutoring. We made significant headway on the reduction of the OH/IR and PPN observations. After lunch, I attended the afternoon lectures. At dinner, my roommate, Donna, said she was going to walk around the

Figure 9: Data, data, and more data...

dish, so I joined her. There were places where I could reach over and touch the dish. The perforated aluminum sheets were identical to our eighteen-meter dish skins on Table Mountain in Boulder, CO, except for the shape. Ours are generally pie-shaped, whereas the Arecibo sheets are more rectangular. The Arecibo dish, the Table Mountain dishes, and the Haswell dish were built by the same engineering firm.

Figure 10: A view from down under.

We returned to the control building and informed the operators we were going to fetch hard hats and go under the dish. I believe it is easier to grasp the enormity of the dish from underneath than from above or standing right next to its edge. There is a key hole in the very center of the dish. Skins are not needed there as the feed platform obscures this area. There were several feed horn mounts for testing the feeds above. From many angles, it was possible to see into the Gregorian dome. Just about anywhere I looked was an incredible view.

The jungle under the dish was as thick as the jungle surrounding the dish in areas not used for maintenance. There were no birds under there but the Coqui frogs were certainly plentiful. The spiral road leading back up got my glutes acting up again. Oh well, no pain no gain...

Thursday morning was also designated for project data reduction. My teammates gathered, and Murray, unfortunately, had to repeat much of what he taught me for the benefit of the others. However, progress on the astronomy went quickly. The emerging science became quite captivating. I took this information with me to the afternoon's lectures where, I must confess, I ruminated over it more than I should have during the presentations. However, the banquet that evening was

a definite highlight. The food was delicious, the keynote speaker was marvelous, and the social after on the museum observing deck was crowned by a feed platform light show. In the quickening evening darkness, the light show was as dramatic as some fireworks shows. Simply, it was beautiful.

Figure 11: Simply beautiful.

I spent the major portion of Friday finishing the the data analysis and working with the boys on our presentation slides which didn't leave time for the final lectures. Finally, all the project teams made their presentations. My team's presentation can be found on the DSES website at `https://www.spesi.org/wp-content/uploads/2016/02/OHIR5GHzMasers.pdf`. All the presentations were excellent and everyone did very well talking through them.

Figure 12: My team's presentation.

Supper was singular as it was the last night of the school. All of us made new friends and colleagues. I discussed the research possibilities of our eighteen-meter dishes with several of the NAIC astronomers. One suggested we would be a great match to the Jodrell Bank fifty-foot dish studies of the decay rate of the Crab supernova decay. Once we get our tracking smoothed over, I will get us connected up. Looking back on the week, I realized just how special this opportunity was. The faculty was knowledgeable, kind, and generous. Murray was remarkable. If I could do it again I would, without reservation.

Saturday, Ashley, Julia, a Cornell Ph.D. astronomy student, she finishes in September, who was a stand-in lecturer on pulsars, drove back to San Juan. We brought Julia to the airport, and Ashley

Figure 13: The final dinner.

and I drove on to Old San Juan. We visited the fort, shopped (great dresses, girls), and found the Parrot Club - *absolutely the best mojitos ever!* We met several of the summer school students and faculty, and partied. I was the first to leave but not by choice. Oh well, plane schedules can be such a bother... I highly recommend the NAIC/NRAO Single-Dish Summer School. It was hard work, hard fun, and the time of my life.

Figure 14: The Parrott Club - mojitos, mojitos!

I want to Thank Ashley Zauderer for allowing me to use her photos!