NATIONAL ASTRONOMY AND IONOSPHERIC CENTER
ARECIBO OBSERVATORY
Cornell University

Research Experience for Undergraduates Program
Annual Report for Award #0852113

PROGRESS REPORT SUMMER 2010
(Written by Angel A. Acosta Colon, REU Coordinator)

1. The Arecibo Program

Introduction

The National Astronomy and Ionosphere Center (NAIC) has conducted a summer student program at the Arecibo Observatory since 1972. It was initially funded through NAIC's operating funds from the NSF, but since 1987 most students have been funded under the NSF Research Experience for Undergraduates (REU) program. Every year, the Arecibo Observatory organizes a REU summer program to give students the opportunity to experience the life of real scientists. The program has a duration of ten weeks, starting at the end of May until mid-August. During this period the students are exposed to real research situations in the different fields of study such as electrical engineering, astronomy and atmospheric sciences. Each student is individually mentored while he or she participates in a scientific (or engineering) project, and gains direct experience of scientific research and its methods. At the end of the summer, every student makes a presentation about his/her project to the scientific staff and their peers. Angel A. Acosta Colon, a faculty member on leave from the University of Puerto Rico, served as the on-site coordinator for the program.

There were 11 students in the summer program of 2010 from universities in the United States and Puerto Rico. Seven students were funded under the NSF REU program, two graduate students under NAIC funds, one graduate student by West Virginia University and one undergraduate by La Fundacion Comunitaria de Puerto Rico and Yale University. The REU-funded students were selected in a competitive process from 114 applicants (91 indicated preference for Radio/Radar Astronomy; 15 for Atmospheric Science; 5 for Computer Sciences and 3 for Electronics). In addition to the REU students, there was one teacher from the local Arecibo Public School district system under the Research Experience for Teachers (RET) part of NAIC's REU grant.

The students attended a safety and conduct seminar conducted by Wilson Arias and Maria Judith Rodriguez (respectively), followed by a welcome BBQ with all the staff. They were also given a tour of the 150-m high telescope platform and the entire Observatory site, including the Angel Ramos Foundation Visitor Center to learn about the history of the Observatory and to view exhibits of the research done at Arecibo.

Every student had the opportunity to participate in a hands-on-experiment with the 305-m telescope. The research group interns all participated, including those with primary interests in computing and engineering. The astronomy students also joined with their mentors while they made observations in their own programs.

Members of the staff and visiting scientists and engineers provided a series of seminars specifically for the summer interns on topics related to recent research in astronomy, planetary studies, atmospheric sciences, electronics, and even the geology of Puerto Rico. Observatory staff speakers included Chris Salter, Robert Minchin, Tapasi Ghosh, Ellen Howell, Mike Nolan, Ed Churchwell, Luis Quintero, Ganesan Rajagopalan, Dipanjan Mitra, Julia Deneva, Jonathan Friedman, and Michael Sulzer. Visiting speakers included Karl Warnick and Brian Jeffs (Brigham Young U.), German Cortes (Cornell/NAIC), D. J. Saikia (NCRA-India), Ron Richards (UPR-Humacao), Stephen Floyd and Robert Jacobsen (HAARP), Mayra Lebron (UPR-Rio Piedras), Katie Richardson (U. New Mexico), Abel Mendez (UPR-Arecibo), and Rendong Nan (FAST, China).

As part of the REU experience, students were required to make a twenty-minute presentation at the end of the program to describe their project, its development, data acquired and its analysis/interpretation. Nick Jimenez gave a poster presentation at the Division of Planetary Sciences in Pasadena in October. Scott Barenfeld, Derek Felli, Deborah Schmidt, Tim Taber, and Chelsea Vincent all presented posters at the January American Astronomical Society Meeting in Seattle. David Gonzalez Alcantara attended the 2010 Coupling, Energetic, and Dynamics of Atmospheric Regions (CEDAR) meeting in Boulder, Colorado.

The Arecibo Observatory is set in forested, limestone karst terrain, and is approached by a winding road along a valley between small hills. While these help isolate the site from radio frequency interference, the nearest “village” (Barrio Esperanza) is ten minutes away by car, while Arecibo is about half an hour away. As has been the norm for the past few years, all the students stayed on site in the Observatory Visiting Scientist Quarters (VSQ). This is helpful for their research activities, but it does limit their ability to travel on the Island, as most students are younger than 25 and find it difficult to hire a car economically. Students were driven to the grocery store and shopping mall twice per week.

This summer several activities were organized on site as well as outside of the facility. An event was normally organized each weekend to allow students to get away from the Observatory to sample the life and sights of Puerto Rico. Activities included a visit to the Camuy Caves and its river, trips to beaches around the island such as Luquillo, Manati, Arecibo and Guanica, and a weekend trip to Culebra Island. They also took sightseeing and hiking trips in the Guanica Dry Forest and El Yunque Tropical Rainforest, a canopy and zipline tour at the Toro Verde Adventure, a visit to Caguana Indian Park in Utuado and to San Juan to explore the nightlife of the metro area. During the month of July, the students received a visit from REU students working in the El Verde Institute located in El Yunque Tropical Rainforest.

We acknowledge and thank the Observatory staff members, Wilson Arias, Carmen Segarra, Carmen Torres, Jose Cordero, Maria Judith Rodriguez, Lucy Lopez, and all the guards for their cooperation and time in assisting with the day-to-day needs of the students. Also, special thanks to Dr. Ji-hyun Kang and Dr. Robert Minchin for their collaboration with the summer students and to Jill Tarbell (NAIC/Ithaca) for managing the application process and student travel arrangements.

Tom Devine, Tim Taber, Chelsea Vincent, David Gonzalez, Deborah Schmidt, Scott Barenfeld, Nicholas Jimenez, Derek Felli, Brandon Fetroe

2. Research Projects

REU-funded Students:

SCOTT BARENFELD (sophomore, University of Rochester)
Project Title: *Reduction of GALFACTS Data and Variable Radio Sources*
Advisors: *Drs. Tapasi Ghosh & Chris Salter, NAIC*

Scott worked with Drs. Tapasi Ghosh and Chris Salter on analyzing Galactic ALFA Continuum Transit Survey (GALFACTS) survey data, looking for variable radio sources. This project involved writing computer code to turn raw GALFACTS data into a list of radio sources. The hope is to use this list to find sources with variable flux density. The data generated by GALFACTS will be used to statistically study variable sources, to try to constrain physical models of how the intensity of these sources change.

After a few days at the beginning of the summer reading about variable radio sources, and radio astronomy in general, Scott began working on his code. The raw data was divided into 2048 files by channel number. The sky temperature for all four Stokes' parameters, I, Q, U, and V, is listed, as well as right ascension, declination, and time. The first step was to calculate an average value of I, Q, U, and V for each channel. Next, bad channels and channels with RFI were flagged. Channels with RFI were found by first using convolution to flatten the I, Q, U, and V spectra, then using a cut-off of six sigma above or below the mean of each spectrum to pick out RFI spikes. A list of the good channels was then generated and this was then used to generate I, Q, U, and V averages. After filtering the data to reduce noise, sources were picked out for the I data by looking for any I values above 8 times the theoretical noise. The three polarization time series were temporarily ignored, because it was much more difficult to pick out sources for them. Once a list of potential sources was generated, Gaussians were fitted to them, and the sources, along with their position in the sky, time at which the peak was measured, and fitting parameters were split into two groups. This was done based on the chi-squared value of each fit, and a list of good (point sources) and bad (extended sources or sources at the edge of the time series) fit sources was generated. Next, these lists were sorted by right ascension, so that each source could be mapped and a total flux could be measured. This was all done on only one day of data at first, as a test. After the program was able to do all this successfully, it was run on data from multiple days, and larger lists of good and bad sources were generated.

This was all that there was time for during the summer. Future work on this project will involve finding a way to deal with polarization, and a way to fit the extended sources to multiple Gaussians. A complete version of the program can then be run on a larger amount of data, to create a list of sources from the entire GALFACTS survey. From this list, sources must be mapped two-dimensionally and flux densities must be calculated. From these flux densities, variability of the sources over days, weeks, and months can be studied, in an effort to understand what causes this variability.

Scott presented a poster at the 217th American Astronomical Society Meeting in Seattle in January.

DEREK FELLI (junior, Brigham Young University)
 Project Title: *The Merging Galaxy Arp220*
 Advisor: *Drs. Tapasi Ghosh & Chris Salter, NAIC*

Arp 220 is a radio emitting galaxy merger, meaning it consists of two galaxies colliding. Derek was assigned to work with long baseline interferometric data from Arecibo and European telescopes. Interferometry is a method to combine signals received at different telescopes to achieve high-resolution observations. He used AIPS to reduce the data, which was taken on Arp 220 with phase calibration referencing. He ran tasks to apply corrections to the data so it was suitable for imaging the radio continuum emission of the region and the absorption and emission lines coming from OH-MASERs. Derek and his advisors were looking for detections of these OH lines. They mapped

the continuum emission of the ARP220 galaxy and found many strong supernova remnants that others had previously noted. The search for absorption and emission lines is still ongoing and it is planned to submit final results for publication.

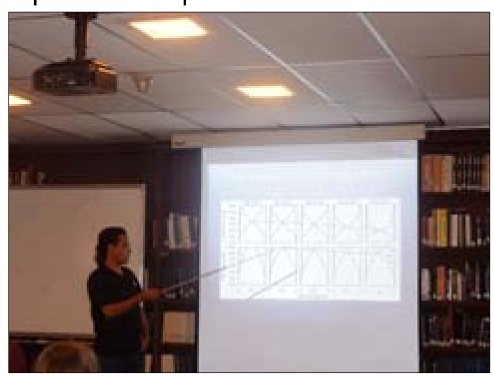
Derek presented a poster at the 217th American Astronomical Society Meeting in Seattle in January.

DAVID GONZALEZ ALCANTARA (senior, at University of Puerto Rico-Mayagüez)

Project Title: *Variability of the Transition Height Over Arecibo Due to Solar and Geomagnetic Activities*

Advisor: *Dr. Christiano Garnett Marques Brum, NAIC*

Along with his advisor, David worked with incoherent-scatter radar data from the topside ionosphere-and-protonosphere at the Arecibo Observatory. The data analysis was performed assuming H^+, O^+ and He^+ ion fractions. The data contain measurements on dates from 1997 to 2009. The work was focused in the behavior of the transition height (ht) due to solar and geomagnetic variations. The topside ionosphere lies above the F2 peak and merges into the protonosphere where H^+ ions dominate. The ion–electron plasma assumes a distribution close to that appropriate to diffuse equilibrium under gravity, with departures from diffusive equilibrium arising from the effect of such factors as neutral winds and electric fields. At this region the main conversion process is the charge exchange reaction (O^{++} H <-> O^+ H^+). A considerable fraction of H^+ may also be produced by direct photoionization of neutral H by the solar EUV radiation of wavelengths less than 91nm, implying a strong dependence of the H^+ and O^+ concentrations with solar activity. The ht is defined as the altitude were the O^+ and H^+ concentrations are equal. This is also the transition between the topside ionosphere and protonosphere. Several cleaning procedures were employed in order to remove bad records using Fast Fourier Transform method. The main results are listed below:



- The variation of ht with the solar activity implies different rates with local time, being stronger before midnight local time;
- The largest variations of all the ion fraction rates with the geomagnetic activity were detected soon after midnight local time. At the same local time, the formation of He^+ with increased geomagnetic activity was detected.
- The variation of ht with the geomagnetic activity presents different responses with solar activity. For lower solar activity, the major variation of ht was about 44 km lower versus 244 km higher depending on solar activity for the same time of day.

During his time in the REU program, David participated in the 2010 Coupling, Energetic, and Dynamics of Atmospheric Regions (CEDAR) meeting in Boulder, Colorado.

NICHOLAS JIMENEZ (sophomore, Alfred Univ.)

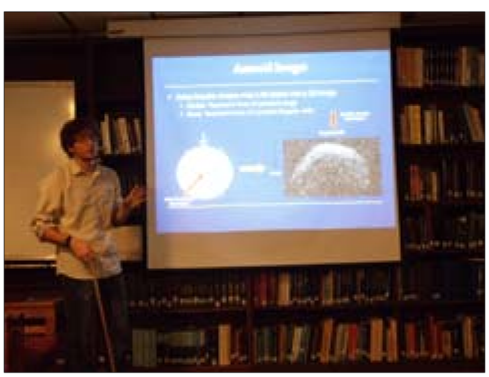
Project Title: *Radar Shape Modeling of the Binary Near-Earth Asteroid 2000 CO101*

Advisors: *Drs. Ellen Howell, Mike Nolan & Patrick Taylor, NAIC*

Nick's project involved the analysis of radar and spectroscopic data taken with the Arecibo radar system and the IRTF. His goal was to make a 3D model of the primary in the binary near-Earth asteroid 2000 CO101 (hence referred to as CO101) using the program Shape and to do thermal modeling to learn a variety of things about the asteroid. Nick and his advisors were motivated to do this for CO101 because it is an asteroid type that is very rare, Xk, which makes up only about 10% of asteroids. They knew that it was probably made out of metal, but knew very little about the type of metal or much else about it. Most asteroids, made up of rocks composed of pyroxene or olivine, have a complex spectrum, but the spectrum of CO101 is very red-sloped and featureless, not telling us too much. So, if they were able to make an accurate thermal model, they would be learning a lot about the composition of the asteroid and the properties of the surface. Making an accurate Shape model would also help to inform the thermal model, supplying better approximations of the radius and pole orientation.

The first thing that they did was to analyze the spectrum taken at the IRTF in September of 2009. Nick learned a great deal about the parameters that govern the model, like the beaming parameter, thermal inertia, and albedo. It was challenging to find a good combination of the parameters to give a satisfactory model, as modifying each parameter affected the model in different ways, and sometimes the same way, so it could be difficult to determine which parameters are responsible for particular effects in the model.

After they did thermal modeling, they progressed to shape modeling. Shape is a powerful tool for making 3D models, but it can be difficult to learn to use. There are many challenges with getting the data into the program. They started out by making ellipsoidal fits, which assume an ellipsoidal shape while only allowing three parameters diameter, flattening, and elongation as well as the pole and rotation rate to float. With this type of modeling, they were able to identify a pole that worked pretty well, and used this pole to learn more about the orbit of the secondary. At this point, they were able to determine quite a few things about the asteroid system, including the primary and secondary diameters. However, the ellipsoid models themselves were not fitting the data very well. This is mostly because of the quality of the data. CO101 was observed with only one day of full power, and then three days of low power observations. This greatly hinders the strength of the data, and a strong data set is necessary for good Shape modeling. Fortunately, the Goldstone Observatory had also taken observations of CO101, and was able to provide their data to help supplement the models. However, integrating their data into Shape proved to be a much more difficult process. Their data format is much different than Arecibo's, so converting it to the format that Shape requires was a challenge, and Nick used a lot of the summer trying to accomplish this.



At this point in the summer, Nick was working with Perl, a programming language with which he was very new, attempting to convert the Goldstone data into radar data format (rdf) files for Shape to read. The goal was to take the information from the drive, log, and ephemeris files and organize them in a header file which the program “hdrrunnum” can read and then make a script which makes rdf files. Hdrrunnum was made to read Arecibo files, so he had to make sure that the Goldstone data could sufficiently resemble them to be able to convert the Goldstone data correctly. This was a much more difficult task than he had originally anticipated. Being his first real programming project, he was unaware of many strategies to use, like being able to make a separate program for each element that he wanted to take from the drive file and then make a script to run all the programs. He was not aware of that strategy until Dr. Chris Magri (U. Maine) came later in the summer, and once Nick started employing that strategy everything became a lot easier. At the end of the summer, he was able to convert one image from Goldstone into a usable rdf file, but was unable to do it for all of them. Dr. Magri was able to get the other images working as rdfs and then Nick was able to run Shape using the new Goldstone data.

Using Goldstone proved to be valuable, as Nick and Dr. Magri were able to progress to more realistic spherical harmonic fits, but in order to get an even more realistic model, they decided to adopt the model for the binary near-Earth asteroid system 1999 KW4 as a starting point. 1999 KW4 is one of the best modeled asteroid systems; there is a lot of data, so much so that even the secondary was able to be modeled. They used the model for the primary, holding all the vertices constant and allowing only the diameter, flattening, and elongation to float, thus allowing the size to float. They arrived at much more reasonable results using this method.

Nick presented a poster at the Division of Planetary Sciences meeting in Pasadena in October 2010.

DEBORAH SCHMIDT (sophomore, Franklin & Marshall College)

Project Title: *Timing and Profile Analysis of RRAT J0627+16*

Advisors: *Dr. Julia Deneva, NAIC, & Dr. Dipanjan Mitra, NCRA-TIFR)*

The discovery of rotating radio transients, more commonly known as “RRATs”, was first announced by McLaughlin et al. in 2006 as a result of the discovery of 11 such objects in the Parkes multibeam survey of the galactic plane. Each of these objects was a spurious radio pulse emitter, with quiescence time between pulses ranging between 4 minutes and 3 hours on average. Periods ranging from 0.4 to 7s were fitted to these objects, leading the astrophysicists studying them to classify them as a type of neutron star. RRATs are like pulsars in the sense that they act as intergalactic lighthouses, emitting beams of radiation as their magnetic poles pass through our field of view. However, unlike pulsars, not every pulse is “seen” as the RRAT’s pole passes in front of our field of view. Each pulse that received is an integer number of periods apart; however, the reception of these pulses is far more sporadic than that of pulses from normal pulsars.

It is currently not understood why RRATs should be such sporadic emitters; therefore, trying to determine the reasons for this is an actively pursued field of research in pulsar astronomy today. One possible explanation behind this is that RRATs are not “true” RRATs at all; that is, it is physical biases that are affecting the ability to see every pulse of the RRAT and not an inherent condition of the emission mechanism. For instance, although the average pulse profile of a pulsar is remarkably stable, each individual pulse can vary widely in shape, width, and intensity. Therefore, if an RRAT is far enough away, the reason for which every pulse is not seen may simply be because these pulses are not bright enough to be picked up by the telescope receivers. One piece of evidence that gives credence for this being the case is the analysis of several RRATs which, while seen as RRATs at lower frequencies, can be viewed as normal pulsars at higher frequencies. The flux density of the radio emission is inversely proportional to the frequency so that, as the frequency of the light goes up, the flux density of the light decreases. Therefore, higher frequency emission from pulsars can appear weaker than emission from lower frequencies, and only the brightest single pulses at higher frequencies may be visible if the distance between the pulsar and Earth is great. Another explanation for the type of emission that is seen from RRATs is that RRATs are dead pulsars that are reactivated by the accretion of matter, say through a disk of asteroids orbiting the pulsar. Finally, another possibility is that RRATs are governed by a completely different emission system from pulsars, so that there is something fundamentally different about a RRAT’s emission mechanism.

In order to test these different theories, it is necessary to gather statistics about these objects that will allow their emission mechanisms, structures, and systems to be accurately modeled. However, as of today, very few RRATs have information like period, period derivative, position, and distance known to very accurate values, so there is still much work to be done in order to accurately catalogue information about many of these objects.

J0627+16 is one such RRAT for which accurate information was not yet known, and which may have been a promising candidate for helping to better understand RRAT emission mechanisms. At the time Deborah started the problem, the period had been estimated to 2.180469, the RA to 06:27:13.1319, and the declination to 16:12:32.0711. Therefore, one of her goals for the summer was to come up with a more accurate timing and position solution for it. The basic idea behind radius-to-frequency mapping for normal pulsars is that higher energy emission takes place at lower emission heights, and because the pulsar beam is believed to be conal shaped, the pulse width for higher energy emission will be narrower. For normal pulsars, there is a power law that describes this: $W \alpha \nu^{-\alpha}$. On average, α is -0.3 for normal pulsars. In order to see whether or not the same idea was applicable to RRATs and help provide a link between RRAT emission and pulsar emission, the other goal of Deborah’s project was to determine if the width of the pulse (indicative of the radius of the emission cone) decreased with increasing frequency, and, if so, what the α value would be.

Deborah analyzed 8 observations of J0627+16 taken with the Arecibo telescope at 327 MHz and 1400 MHz, respectively. First, she looked for any single pulses she could find within each observation whose signal-to-noise ratio was greater than 5. She then separated pulses from the RRAT itself from mere RFI by plotting a histogram of number versus phase and looking for a huge spike, which would indicate the phase at which all the pulses from the RRAT would fall. She recorded the arrival times and widths for these pulses, which were then inputted into the timing software package TEMPO in order to determine as accurate a period, period derivative, dispersion measure, and position as possible. The pulses from each observation were then phase-binned and added together in order to create an average pulse profile. Finally, once she had average pulse profiles for each observation, she took the profiles for observations taken at the same frequency, shifted the pulses in each observation so that they would occur at the same phase, and added them together in order to create two average pulse profiles, one for 327 MHz and one for 1400 MHz.

As a result, Deborah was able to determine a perod for J0627+16 of 0.4586119214451020 sec with an error of +/- 0.0000000000216175, a DM of 112.231136 with an error of 0.014841, an RA of 06:27:18.25005842 with an error of 0.06289086, and a declination of 16:09:33.8858572 with an error of 9.0156842. She was unable to determine a period derivative for the RRAT, as it seems that the period derivative was so small, there was no significant change between the expected arrival times of pulses in subsequent observations and their actual arrival times due to a change in period (which is how period derivative is calculated). However, she did manage to set an upper limit on what the period derivative of the RRAT could be. Furthermore, she was able to get two average pulse profiles at 327 MHz and 1400 MHz and was able to determine that the pulse width at 327 MHz was at least 40.68 degrees (out of 360 degrees), while the pulse width at 1400 MHz was 22.176 degrees, which shows preliminarily that the pulse width also decreases with increasing. From this information, she was able to calculate an α value of 0.417. While these are promising preliminary results, it is necessary to take many more observations, as the number of pulses used to determine this information is quite small and more single pulses are necessary in order to get increasingly more accurate information.

Deborah presented a poster at the 217th American Astronomical Society Meeting in Seattle in January.

TIMOTHY TABER (junior, Vassar College)

Project Title: *The Arecibo Galaxy Environment Survey – HI Observations of the Isolated Galaxy UGC 2082*

Advisor: *Dr. Robert Minchin, NAIC*

Tim worked on data from the Arecibo Galactic Environment Survey (AGES), with his mentor Dr. Robert Minchin. More specifically, Tim was analyzing the data surrounding the isolated galaxy UGC 2082. AGES is a neutral hydrogen (HI) survey using the ALFA receiver at the Arecibo Observatory. The ALFA receiver is an L-band seven-feed array offering faster survey speeds than previous single-feed receivers by looking at seven points simultaneously. Because of the 100-MHz bandwidth used by AGES, a three-dimensional data cube is created of each field due to the redshifting of the 21-cm line of HI. Tim's project for the summer was to search for and analyze sources in the data cube surrounding UGC 2082. Since AGES reaches out to heliocentric velocities of almost 20,000 km/s and UGC 2082 is located at 696 km/s most of the sources found were behind the galaxy. The positions of these galaxies give us insight on the HI mass function and large-scale structure of the universe. A search for potential low surface brightness galaxies near UGC 2082 was also conducted.

During the initial search through the data, Dr. Minchin and Tim found 90 HI sources. The spectrums for each source were plotted and fitted by the mbspect routine in Miriad. Tim used the heliocentric velocity and HI flux value for each source to calculate the HI mass of each source. The majority of his time during the 10 weeks was spent searching for optical counter-parts for the sources. This search was prolonged by problems getting photometric data from Sloan Digital Sky Survey images downloaded from the U.S. Virtual Observatory. After obtaining the SDSS images directly from the SDSS website, he was able to use Gaia to perform aperture photometry on each of the sources to find an apparent magnitude in the G and R filters. For sources not within SDSS fields, and for a check on all other sources, he used SuperCOSMOS to find the B and R magnitudes. He then used the apparent magnitudes, Hubble's Law, and the distance modulus to calculate absolute magnitudes and luminosities for each source. The HI mass to luminosity ratio was calculated for each source in each filter and used to narrow down the possible optical counterparts. Twenty-four of the HI sources did not have clear optical counterparts. The HI minus optical coordinate offset was plotted to be sure all of the sources fell within one beamwidth of the receiver. The most likely optical counterparts were chosen for each HI source, sources were marked if they had multiple possible optical counterparts.

Also plotted was MHI/L vs. Luminosity. As expected, this relationship had a negative slope showing that more luminous spiral galaxies have a lower ratio of HI for their size. There was a faint source in the data at 590 km/s, which was very close to UGC 2082 at 713 km/s. The angular separation between these two sources was 66.5 arcminutes. Using a Tully-Fisher distance to UGC 2082 and assuming this was a companion, Tim calculated a physical separation of 284.4 kpc. If UGC 2082 was the Milky Way, this companion would be in our local group somewhere between the Large and Small Magellanic Clouds (~50-60 km/s) and the Andromeda Galaxy (~800 km/s).

Tim also plotted right ascension and declination versus heliocentric velocity to produce a wedge diagram showing structure in the data cube. This showed there is a clear concentration of galaxies at approximately 5500 km/s and another around 11000 km/s. This concentration appeared both in the RA and Dec plots. This result can be used to study structure of the universe.

Follow-up observations will be done when the field is visible in the night sky from Arecibo. These will be done using the L-Wide receiver and will look at dubious sources found in the original search through the data cube. HI sources without optical counterparts will also be looked at. These observations will confirm whether or not these sources are real.

Tim presented a poster at the 217th American Astronomical Society Meeting in Seattle in January.

CHELSEA VINCENT (sophomore, University of Pittsburgh)

Project Title: *Studying the HI Emission of Supernova Remnants in the I-GALFA*

Advisor: *Dr. Ji-hyun Kang, NAIC*

Chelsea used I-GALFA data, taken at the Arecibo Observatory, to study supernova remnants (SNR) within the inner galaxy. These SNRs were observed in HI emission, the 21cm wavelength radiation that indicates the presence of neutral hydrogen. The preliminary step involved examining thirty-eight cubes from the I-GALFA data where known SNRs existed. These cubes were 3-D plots of HI emission intensity along galactic longitude and latitude as a function of velocity. As Chelsea scrolled through a velocity range of -150 km/s to +150 km/s, she was able to see how the HI structure changed as the velocity varied. If a shell-like structure was found, she would note the name of the SNR and the velocity range over which it was observable. She also noted any central emission or absorption seen in the location of the SNR. For emission that appeared to be SNR related, velocity channel maps were created. In addition, the radio continuum images of the regions were uploaded as contour maps and placed over the HI images to see if the HI emission corresponded to the SNR visible in the radio continua emission.

For the most promising images, the previous studies of the known SNR in that region was researched to see what kind of observations and results had already been done. The SNR G65.3+5.7 was chosen to focus on because of how well the HI emission was associated with the radio continuum and because of how few references there were on the SNR, none of which had observed the remnant in HI. This object was then analyzed using the kvis tool and the IDL programming language to derive parameters such as HI shell mass, radius, hydrogen number density, expansion velocity, and age. The table below summarizes the values of these parameters.

SNR G65.3+5.7	
HI Shell Mass	~2,000 smu
Radius	130' or 38 pc
HI Number Density	0.353 cm^{-3}
Expansion Velocity	550 km/s
Age	~21,000 yrs

With some extra time available, Chelsea also began analysis on the SNR G54.4-0.3. A total HI mass of 58.59 smu was calculated for the velocity range where HI emission was observed (between 85 km/s and 110 km/s). The last few weeks were spent trying to fit a gaussian curve to the data in hopes of integrating over this curve and deriving a total shell mass. However, the data points were not converging to the fit, and therefore this value has not yet been determined.

Chelsea presented a poster at the 217^{th} American Astronomical Society Meeting in Seattle in January.

RET Teacher:

KETHY TRUJILLO (Arecibo School District)
Advisor: *Hector Camacho (NAIC)*

Ms. Kethy Trujillo, a high school science teacher for the Arecibo School District, was our 2010 Research Experience for Teachers (RET) participant. Kethy read selected publications about the ionosphere written by atmospheric scientists who are users of the Arecibo Observatory. From this material, a 90-minute workshop about the ionosphere was developed and adapted to school children in the years 7-9 and 10-12. The content of the workshop materials was matched to the Puerto Rico Department of Education Standards for Excellence. The workshop materials were designed to immerse the student in the general facts about, and peculiarities of, our atmosphere and how the research conducted at Arecibo is of importance to our understanding of atmospheric phenomenon. The workshop deliveries included a Power Point presentation, a teacher/student workshop manual, and three well-developed hands-on activities. The workshop was presented to a selected audience from the Arecibo staff, which gave it a very positive review. This workshop will be added to the Visitor Center workshop offering for visiting school groups.

Kethy was very enthusiastic about the project assigned to her and very thankful for the opportunity. She mentioned that the experience gained during her RET appointment at the Observatory helped her to develop skills on curriculum design in many positive ways. She also expressed her gratitude for working closely with a scientist – a unique career experience for her.

Puerto Rico Funds:

EMY RIVERA (freshmen, University of Puerto Rico at Rio Piedras)
Project Title: *Chemistry Survey of the Star Forming Region W51 IRS1*
Advisor: *Mayra Lebron (UPR Rio Piedras)*

Emy worked in a chemical survey being done on the star forming region W51IRS1. It basically focused on finding new and already known recombination lines in the area. The first part of the survey used the 800-MHz receiver and this past summer other receivers began to be used. Emy's task entailed reducing the data gathered during the observations and sometimes participating in the observations. Different Hα recombination lines were found and some CH lines also were found. Observations were made using the position switching method and the Mock spectrometer. Information gathered in this survey will be helpful to determine the optical thickness and/or thinness of the region.

Emy's participation was funded by La Fundacion Comunitaria de Puerto Rico and Yale University

NAIC Funds:

THOMAS DEVINE (1st-yr graduate student, West Virginia University)

Project Title: *Data Management Facilitator: A Software to Data Storage Automation*
Advisor: *Dr. Arun Venkataraman, NAIC*

Tom was given the task of automating the data copy and hard drive swap out procedure for the Mock backend fileservers. The current state of the process upon his arrival required meticulous input for each of the fourteen servers that spanned two separate command line interfaces. The main tasks he set out to automate were adding a drive, copying the data collected on the server, and removing a drive.

Tom decided to write the control software in Java, as he thought he could get it to work and could make a pretty good graphical user interface (GUI) in that language. Also, the task seemed rather daunting in size and he thought that learning a new language on top of that would make it impossible for him to complete the code in the given timeframe. He developed the software using the Eclipse: Galileo IDE, which allowed him to simultaneously create, and publish to the Internet, an intricately detailed and easily navigable API for the software.

The GUI Tom created is a drastic improvement over the manual process and is currently being beta tested in his absence by Dr. Arun Venkataraman, head of the Arecibo Observatory Computer Department. It allows the user, once logged in, to remotely connect to the pdevs servers via SSH. The connection takes place behind the scenes and requires only that the user enter the name of the server once, as connection information is stored in a properties file when the program is not in execution. All connections occur concurrently and the user is only notified if a problem occurs. After connecting, it displays drive configuration information acquired from the selected remote host on the main GUI. This information is maintained by the program for every connected host, but only displayed for the selected host.

The user is offered a variety of controls allowing host addition or removal, drive addition or removal, scheduling of copy operations, manual initiation of a copy operation, and the viewing of remote system log files or application log files. When the command is given for a drive to be added, the program automatically goes through the lengthy process of adding the drive. It scans the configuration information to find the open drive, adds it to the RAID controller, adds it to the SCSI subsystem, partitions the drive, makes an xfs file system on the drive (first issuing a warning if a file system already exists), and finally mounts the drive to the kernel. All this is now performed by pressing a single button.

Upon successful completion of the addition of a new drive, a new copy schedule is computed for that drive. The program examines the most recent telescope schedule stored on the hard drive and computes windows when the selected drive will not be in use. Copy timers are then set up to perform the copy procedure within those windows, with a monitor to ensure they are cancelled before they approach too near the end of their scheduled window. The user is provided controls to abort or edit any scheduled copy operation. In the event that a hard drive is filled to capacity before all files are copied, that drive is automatically prepared for removal from the server and an e-mail notification is sent to the registered e-mail address prompting for physical removal of the drive. The program maintains a list of all copied files that is double checked for accuracy before a hard drive is removed. This list also serves as a master list for deletion of files from the permanent drives, a task which is reserved for human performance. A detailed, rolling log file is maintained for all operations performed by the program. This log provides oversight for the software and facilitates any debugging that may still be required.

All in all, the software automates the file copy and drive changing procedure among the fourteen servers to the point that the task could be performed by an individual without expert knowledge of the systems or inner machinations. Drive addition, copying during available windows, and removal is all set in motion by pressing a single button for each of the remote hosts.

BRANDON FETROE (2nd-yr graduate student, Stanford University)

Project Title: *Velocity Estimation of Multiple Ion Species in the Topside Ionosphere*
Advisor: *Dr. Michael Sulzer, NAIC*

Incoherent scatter from electrons is routinely used to measure many characteristics of plasma in the atmosphere, such as the density and temperature of O^+ or H^+ ions at various altitudes. These plasma parameters are traditionally determined by least-squares fitting the measured data to the theoretical spectrum or autocorrelation function (ACF) that corresponds to scattering from a theoretical plasma with ion and electron temperature and density set to the estimated values. Most codes and techniques for determining these parameters assume that all species drift together, which maintains the spectral symmetry and simply results in a Doppler shift corresponding to the bulk velocity. As might be expected, ion counter-streaming produces systematic errors for the individual ion velocities, as well as the estimates of temperature and density. The primary goal of this work is to verify and then implement Vickery's modification of Swartz's code which generates spectra that take into account ion velocity independence. This tool is then used to help quantify the deviations produced when assuming a common bulk velocity. This knowledge will allow some general guidelines to be set for when the systemic error is "large enough" to motivate the implementation of this computationally intensive technique.

In 1976 Vickery published his modification to the dressed particle approach for incoherent scatter from collision-less plasma free of magnetic field effects. However, initial implementation of these equations did not reduce to the known result when all ions have the same velocity. To correct this inconsistency, one simply multiplies the Fo terms by the ion fraction. It appears Vickery derived his equation from the earlier equation published by Swartz which contained a misprint that omitted the ion fraction (this was recognized no later than 1978). When the ion fraction correction is inserted into Vickery's equation his results become reproducible, revealing that he probably modified Swartz's code rather than rewriting it from the ground up.

Nonlinear least-squares fitting were conducted on a small number (~30) of generated spectra to obtain the estimation's sensitivity to Gaussian noise. A Gaussian distribution sampled, multiplied by 1/20th of the mean spectral amplitude, and then added to the true spectrum, yielding errors that were within ±25 m/s for H^+ and ±10 m/s for O^+ at 105/cm and 1000K. While a more rigorous error analysis is currently underway, these initial values seem slightly larger than Vickery's stated error of 5-10 m/s, however the lack of derivation or explanation as to how his error was obtained will make detailed comparison difficult. Further research of the systematic error is also currently being explored to establish guidelines for determining when using a simpler, common bulk velocity technique is sufficient.

Other Funds:

JAYANTH CHENNAMANGALAM (2nd-yr graduate student, West Virginia University)

Project Title: *IBOB + IADC Programming and Communication Using CASPER Development Tools*

Advisor: *Luis Quintero, NAIC*

The aim of Jayanth's project was to provide a hands-on learning experience in the use of Field-Programmable Gate Arrays (FPGA), especially the systems developed by the Center for Astronomy, Signal Processing, and Electronics Research (CASPER) at the University of California Berkeley. The specific CASPER boards used were the Interconnect Break-Out Board (IBOB) and the analog-to-digital converter board IADC.

The IBOB houses a Xilinx Virtex-II Pro FPGA chip with embedded high-speed serial transceivers and embedded dual IBM PowerPC 405 RISC processors, dual Tyco Z-DOK+ host adapters, 10/100 Ethernet, dual XAUI/10Gbps CX4 interfaces, and an RS232 port, among others. The PowerPC processors run Tiny SHell, a stripped-down shell for communication with the PC, providing a command line for configuration and file transfer. The IADC board that was used, ADC2x1000-8, is a dual 8-bit 1 Gsps ADC, which can be clocked at 10 MHz–1 GHz.

Jayanth and his advisor, Luis Quintero, used MATLAB R2007b and Simulink, Xilinx ISE 10.1, Xlinix EDK 10.1, and Xilinx DSP Tools 10.1 for the FPGA development, along with CASPER libraries (v10.1). On the PC side, they used Gulp for gigabit-rate data acquisition, and off-the-shelf tools such as Wireshark. They also wrote a few programs for our data analysis.

Jayanth and Luis verified their hardware/software setup using two pre-existing designs, namely the 1-GHz GAVRT spectrometer and the 400-MHz Parkes spectrometer, and the results were satisfactory enough to move on to developing our own designs.

The first design that they built was a histogrammer based on the GAVRT design, in which the FPGA writes 8-bit samples to a shared BRAM. The Tiny SHell code that runs on the PowerPC reads this data, does UDP packetization, and transmits these packets over the 10/100 Ethernet to a data acquisition PC. They faced problems involving data loss, as the 10/100 Ethernet supports a data rate of only up to 12.5 Msps (for 8-bit samples). Nevertheless, they were able to process the acquired data and build histograms of the input signal values (such as sine waves, Gaussian noise, etc.).

The second design was a histogrammer based on the Parkes design, utilizing a 10-Gbps transceiver, to ensure that no data loss takes place. The transceiver packetizes 8-bit samples and transmits the UDP packets to the PC where a 10-Gbps NIC along with Gulp captures the data and writes it on to the disk, from where the analysis program reads it and does histogramming. The design was verified in Simulink, but programming the board led to problems in data quality that are not resolved at this point.

The project documentation, including, detailed description of setting up the system and programming it, can be found on the NAIC Wiki (wiki.naic.edu/twiki/bin/view/Main/CasperDevTools).

Jayanth's participation was funded by an award from the Research Corp administered by West Virginia University.

3. 2010 Staff and Visitor Talks

REU seminar was regularly scheduled each Monday and Thursday, and all the Arecibo Observatory community was invited to attend. We also had the opportunity to welcome speakers from other institutions.

Seminar	***Speaker***	***Date***
The Radio Sky	Chris Salter	June 3
Introduction to Galaxies	Robert Minchin	June 10
Introduction to Radio Interferometry	Tapasi Ghosh	June 14
Geology of Puerto Rico	Ellen Howell	June 17
Next Generation Antenna Feeds for Radio Astronomy	Karl Warnick & Brian Jeffs (BYU)	June 17
AO40 Feasibility Study	German Cortes (NAIC-Cornell)	June 17
Asteroids	Mike Nolan	June 21
Radio Galaxies: Large and Small	D.J. Saikia (NCRA-India)	June 22
Interstellar Molecules	Ed Churchwell	June 24
Caves and Karst of Puerto Rico	Ron Richards (UPR-H)	June 28
High Frequency Active Auroral Research Program (HAARP)	Stephen Floyd & Robert A. Jacobsen (HAARP)	June 30
Massive Stars	Mayra Lebron (UPR-RP)	July 1
Signal Processing Instrumentation – Analog	Luis Quintero	July 8
The Astronomy of Dark Matter	Katie Richardson (UNM)	
Planet Habitability	Abel Mendez (UPR-A)	July 12
Signal Processing Instrumentation – Digital	Ganesan Rajagopalan	July 15
The Mesospheric Refrigerator	Jonathan Friedman	July 20
Detection of Unpulsed Emission in two Long Period Pulsars	Dipanjan Mitra	July 20
Radio Pulsars I	Dipanjan Mitra	July 21

Radio Pulsars II	Julia Deneva	July 21
Incoherent Scatter Radar	Michael Sulzer	July 22
Five hundred meter Aperture Spherical Telescope (FAST) project	Rendong Nan (FAST)	July 28

4. 2010 Summer Student Presentations

Each student presented their research project to the Arecibo Observatory community.

Title	***Student***	***Date***
The Merging Galaxy Arp220	Derek Felli	July 21
Studying the H1 Emission of Supernova Remnants in the I-GALFA	Chelsea Vincent	July 23
Radar Shape Modeling of Binary 2000 CO101	Nicholas Jimenez	July 30
Reduction of GALFACTS Data and Variable Radio Sources	Scott Barenfeld	August 3
Timing and Profile Analysis of RRAT J0627+16	Deborah Schmidt	August 5
The Arecibo Galaxy Environment Survey – H1 Observations of the Isolated Galaxy UGC 2082	Timothy Taber	August 6
Data Management Facilitator: A Software to Data Storage Automation	Thomas Devine	August 9
Velocity estimation of multiple ion species in the topside ionosphere	Brandon Fetroe	August 24
CASPER Development Tools	Jayanth Chennamangalam	August 6
Chemistry Survey of the Star Forming Region W51 IRS1	Emy Rivera	August 9

5. Extra-Curricular Activities

In addition to their research projects, the summer program consisted of cultural and educational activities on the island of Puerto Rico. In addition to the activities listed below, the students had opportunities to enjoy the movie theater, the Arecibo nightlife and some karaoke.

Activity	***Location***	***Date***
Luquillo Beach Trip	Luquillo, PR	May 28
Old San Juan Night Life	San Juan, PR	June 4
La Ventana Cave & Poza del Obispo Beach	Utuado & Arecibo, PR	June 5
REU Welcome Pool BBQ	Arecibo Observatory	June 11
Old San Juan Trip	San Juan, PR	June 12
Angel Ramos Foundation & Visitor Center	Arecibo Observatory	June 16
Toro Verde Adventure Park	Orocovis, PR	June 19
Caguana Taino Indian Ceremonial Park & Mar Chiquita Beach	Utuado & Manati, PR	June 28
Camuy Caves Park	Camuy, PR	July 3
El Yunque : El Verde REU	Luquillo, PR	July 10
Visit to AO from El Verde REU	Arecibo Observatory	July 11

Culebra Island	Culebra, PR	July 17-19
REU Farewell Pool BBQ	Arecibo Observatory	July 30
Bosque Seco & Tamarindo Beach	Guanica, PR	July 31

6. Student's Experience in Their Own Words

Overall I thoroughly enjoyed my stay here at the Arecibo Observatory. I hope to see this program continued for many years because it is a great educational experience for students who, like myself, are interested in pursuing a career in physics and astronomy. I learned very much not only about my project, but also about what a career in astronomy research entails. I look forward to applying the knowledge I have acquired here to my school work in the upcoming semesters and hope to keep in touch with the friendly staff with whom I have been so fortunate to become acquainted. I would like to thank you personally for providing me with this opportunity. I truly appreciate the time I have spent in Puerto Rico and hope this is not the last time I visit the observatory.
--Chelsea Vincent

Working in hands-on observation was one of the things that really help me to understand how the observatory works in all senses. It was very interesting and there is really no other way to understand how the observatory works if you don't do the observations by yourself. The platform tour is the best part of the tours around all the observatory and it really helps to understand the real magnitude and complexity of the observatory.

I'm very proud to be able to work for Cornell University and it will help me a lot on my way to make a career in physic.
-- David Gonzalez

I greatly enjoyed the project I was assigned for the summer. Although I had worked in pulsar astronomy prior to this summer, the research I was performing this summer was completely different and taught me much more about pulsar astronomy than I ever could have expected. My mentors were completely willing to answer any and all questions I might have and taught me an incredible amount of information both on pulsar theory and how pulsar research is performed. They were willing to help me out on any problem I might have and seemed to have an unending amount of patience for some of the problems I faced during the course of my research.

The hands-on observing projects taught me a lot about how observations are done at Arecibo and how to interact with CIMA. I also learned a lot about areas of astronomical research that I had never been involved in before (e.g. searches for recombination lines in extragalactic sources). One of the best parts was how hands-on the projects actually were…the students really were in charge of picking their sources and what they were going to be looking for (although advisors were always there for help). Of course, the observations were also a lot of fun; it was very exciting to get to work alongside friends taking data from the world's largest and most sensitive radio telescope.

Working at Arecibo Observatory was a phenomenal experience. Being surrounded by so many brilliant scientists that were able to help on every conceivable problem truly helped

to make the learning and working process much easier. Further, the staff helped to create a friendly and welcoming environment and truly helped to make us feel like we were a part of the community.
--*Debbie Schmidt*

I was greatly impressed on how well I was welcomed to work here. I enjoyed every day here. The mentors I worked with, Chris and Tapasi, and the others on site were very accommodating. I learned a lot from them. We ran into a lot of problems and sat down together to analyze them and by the end of the summer, I felt like I was contributing on an equal level with them. I am thinking of recommending my brother to apply here particularly because the observatory is full of friendly people, they looked out to make sure we had fun and they are willing to teach the skills to do meaningful research.
--*Derek Felli*

The hands-on projects were a lot of fun and very useful for me. They allowed me to experience subjects in radio astronomy that I would not have experienced with my main project alone. I would strongly recommend that future students take part in these.
--*Scott Barenfeld*

Observing for the individual projects was a lot of fun, it will be very helpful if I ever come back to observe here in the future. I would definitely encourage future students to participate; working with CIMA was a great experience for the future. Arecibo Observatory is a great place to work, I hope I can come back here at some point.

I had a blast this summer in Puerto Rico, we had a great variety of social and cultural experiences.
--*Tim Taber*

As a computer systems guy, I really had no clue what was going on with the observations and had none specifically designed for me. Nevertheless, I attempted to attend every observation made by my peers and found them to be rewarding educational experiences. And it was pretty darn cool to watch the world's largest radio telescope in action!

I loved working for Cornell at Arecibo and would instantly accept even the lowliest on-staff position just to be in such a tremendously fulfilling working environment! Seriously, I'll clean toilets for $2/hour just to be on site! I absolutely loved it there!
--Tom Devine

7. Papers Presented at Meetings and Conferences to Date

Barenfeld, S., T. Ghosh, and C. Salter, *Analysis of GALFACTS Data for the Study of Variable Radio Sources*, American Astronomical Society, AAS Meeting #217, #142.62, Bulletin of the American Astronomical Society, Vol. 43, Jan 2011

Brum, C. G., D. G. **Alcántara**, J. Vargas, and S. A. Gonzalez, *Solar and Season Variability of the Nighttime Transition Height Over Arecibo Based on Incoherent Scatter Radar Data and EUV-UV Fluxes*, American Geophysical Union, Fall Meeting 2010, abstract #SA33B-1777, Dec 2010

Felli, D., C. J. Salter, T. Ghosh, and E. Momjian, *VLBI Imaging of OH Satellite Lines in Arp220*, American Astronomical Society, AAS Meeting #217, #245.10, Bulletin of the American Astronomical Society, Vol. 43, Jan 2011

Jimenez, N., E. S. Howell, M. C. Nolan, P. A. Taylor, L. A. M. Benner, M. Brozovic, J. D. Giorgini, R. J. Vervack, Y. R. Fernandez, M. Mueller, J. Margot, and M. K. Shepard, *Radar Shape Modeling of Binary Near-Earth Asteroid 2000 CO101*, American Astronomical Society, DPS meeting #42, #13.18; Bulletin of the American Astronomical Society, Vol. 42, p.1056, Oct 2010

Schmidt, D., J. Deneva, D. Mitra, and J. Rankin, *Analysis of the Timing and Emission Properties of RRAT J0627+16*, American Astronomical Society, AAS Meeting #217, #336.09, Bulletin of the American Astronomical Society, Vol. 43, Jan 2011

Taber, T. M. and R. Minchin, AGES, *The Arecibo Galaxy Environment Survey (AGES) - HI Observations of the Isolated Galaxy UGC 2082*, American Astronomical Society, AAS Meeting #217, #246.06; Bulletin of the American Astronomical Society, Vol. 43, Jan 2011

Vincent, C. and J. Kang, *Studying The Hi Emission Of Supernova Remnants In The I-GALFA Survey*, American Astronomical Society, AAS Meeting #217, #256.25, Bulletin of the American Astronomical Society, Vol. 43, Jan 2011

8. REU, Other Summer Students & RET Participant Statistics

Participants Status	1972-2009	2010	Total
Undergraduate Level	**280**	**8**	**288**
Graduate Level	**67**	**3**	**70**
RET	**10**	**1**	**11**
		Total Number of Participants:	**369**

Participants Status	1972-2009	2010	Total
Minorities	**80**	**5**	**85**
Women	**151**	**4**	**155**
		Total Number of Participants:	**239**

Number of REU, Other Summer Students & RET Participants – Scientific Field

Scientific Field	1972-2009	2010	Total
Radio/Radar Astronomy	**206**	**7**	**213**
Atmospheric Science	**95**	**2**	**97**
Computer Sciences	**22**	**1**	**23**
Electronics	**22**	**1**	**23**
Education	**12**	**1**	**13**
		Total Number of Participants:	**369**

9. Educational Institutions Represented in the NAIC Summer Student Program

(1972 through 2010)

Agnes Scott College
Alfred University
Amherst College
Arizona State University
Bates College

Bethel College
Boston University
Brigham Young University
Bryn Mawr College
California Institute of Technology
California Polytechnic State University
Cambridge University, UK
Carleton College
Carthage College
Case Western Reserve University
Centenary College of Louisiana
City College of New York
Clemson University
Colgate University
Columbia University
Cornell University

Dartmouth College
Ecole Normale Superieure of Lyon
Embry-Riddle Aeronautical University
Fairmont State University
Franklin & Marshall College
Georgetown University
Globe Institute of Technology

Gorky University, Russia

Harvard University
Haverford University
Indiana University
Interamerican in Bayamon
Johns Hopkins University
Lehigh University

Louisiana State University
Massachusetts Institute of Technology

McGill University, Canada

Miami University, Ohio
Missouri State University

New College of Florida
New Mexico State University
New Mexico Tech
North Carolina State University
Northern Arizona University

Northwestern University
Oberlin College
Oxford University, UK
Pennsylvania State University
University of Pittsburgh
Pomona College
Princeton University
Purdue University
Rensselaer Polytechnic Institute
Rice University
University of Rochester
Rutgers University
Saddlebeck University
Saint Anselm College
San Diego State University
Smith College
Southwest Missouri State University
St. Andrews University
Stanford University
SUNY Albany
SUNY Binghamton
Texas Technological College
Trinity College Dublin, Ireland
Universidad Interamericana de PR
Universidad Metropolitana, San Juan
University of Akron
University of Alabama
University of Arkansas
University of British Columbia
University of California, Berkeley
University of California, Los Angeles
University of California, San Diego
University of California, San Luis Obispo
University of California, Santa Cruz
University of Chicago

University of Colorado
University of Georgia
University of Grenoble, France
University of Hawaii
University of Houston
University of Illinois, Urbana-Champaign
University of Iowa
University of Maryland
University of Massachusetts (Amherst)
University of Michigan
University of Minnesota
University of Montana
University of Missouri in Columbia
University of Nebraska-Kearney

University of Northern Iowa
University of Pennsylvania
University of Puerto Rico, Arecibo
University of Puerto Rico, Humacao
University of Puerto Rico, Mayagüez
University of Puerto Rico, Río Piedras

University of Rochester
University of Texas, Austin
University of Texas, Dallas
University of Toronto (Canada)
University of Virginia
University of Washington
University of Wisconsin-Madison

Utah State University

Vassar College
Villanova University
Virginia Polytechnic Institute
Washington & Lee University
Wellesley College
Wesleyan University

Western Washington University

West Virginia University

Williams College

Wittenberg University
Yale University

10. NAIC Summer Student Participants

(1972 through 2010)

Below is a partial list of former summer students. Most affiliations listed, particularly for the most recent years, refer to the students' affiliations at the time of their REU program. Current affiliations for some former students or teachers are given (if known), particularly for the earlier years.

Participant:	Affiliation:	Year
Dr. Vincent J. Abreu	University of Michigan	1972
Dr. Linda Dressel	Space Telescope Science Institute	1972
Dr. Alan Hirshfeld	Univ. of Massachusetts, Dartmouth	1972
Dr. Thomas Balonek	Colgate University	1973
Dr. James Cordes	Cornell University	1973
Dr. Lee Hartmann	University of Michigan	1973
Dr. Martha Haynes	Cornell University	1973
Dr. William Newman	Univ. of California Los Angeles	1973
Dr. James F. Vickery (deceased)	Stanford Research Institute	1973
Dr. Randy Kimble	NASA/Goddard Space Flight Center	1974
Dr. James Breakall	Pennsylvania State University	1974
Dr. Matthew Malkan	Univ. of California @Los Angeles	1976
Dr. Bruce Wilking	University of Missouri, St. Louis	1976
Dr. Kristen Sellgren	Ohio State University	1976
Dr. Richard L. White	Space Telescope Science Institute	1976
Dr. Robert J. Hanisch	Space Telescope Science Institute	1977
Dr. Keith D. Horne	University of St. Andrews, Scotland	1977
Dr. Leslie Hunt	Arcetri Observatory, Italy	1978
Dr. Emilio Falco	Smithsonian Inst., Whipple Observatory	1979
Dr. Jacqueline Hewitt	MIT	1980
Dr. Richard Edelson	UCLA	1981
Dr. Michael Bicay	NASA/Ames Research Center	1982
Dr. Perry Hacking	Jet Propulsion Laboratory	1982
Dr. Brett Isham	Univ. Interamericana de Puerto Rico	1983
Dr. Michael A. Strauss	Princeton University	1983
Dr. Douglas O. Wood	NRAO Socorro	1983
Dr. Blaise Canzian	L-3 Communications/Brashear	1984
Dr. JoAnn Eder	Arecibo Observatory (retired)	1984
Ms. Inge Heyer	University of Wyoming	1984
Dr. Steven T. Myers	NRAO-Socorro	1984
Dr. Joshua Roth	Winchester High School, Mass.	1984
Dr. Myeong-Gu Park	Kyungpook National Univ., Korea	1985
Dr. Daniel Holden	Los Alamos National Laboratory	1985
Dr. William Reach	SOFIA, NASA/Ames Research Ctr	1985
Dr. Nicholas Stacy	Surveillance Research Lab, S. Australia	1985
Dr. Leila Belkora	Self-employed	1987
Dr. Peter Lawson	Jet Propulsion Laboratory	1987
Dr. Brian A. McLeod	Center for Astrophysics	1987
Dr. Margaret Meixner	Space Telescope Science Institute	1987
Dr. John M. Carpenter	Caltech	1988
Dr. Tracey Evans	Caltech	1988
Dr. Sixto González	Arecibo Observatory	1988
Dr. Richard Collins	University of Alaska	1988

Dr. Margaret Murray Hanson	University of Cincinnati	1988
Dr. Joseph Lazio	Jet Propulsion Laboratory	1988
Dr. Crystal L. Martin	UC Santa Barbara	1988
Dr. Bruce Campbell	National Air & Space Museum	1989
Dr. Jayaram Chengalur	NCRA-TIFR, Pune, India	1989
Dr. Eric Schulman	NRAO Charlottesville	1989
Dr. Adam Showman	University of Arizona	1989
Dr. Thomas E. Vaughan	University of Oklahoma	1989
Dr. Jonathan Williams	University of Florida	1989
Dr. Rachel Akeson	Caltech	1990
Dr. Bryan W. Miller	Gemini Observatory, Chile	1990
Dr. Liese van Zee	Indiana University	1990
Dr. Jeremy Heyl	Univ. of British Columbia	1991
Dr. Jenny Patience	University of Exeter, UK	1991
Dr. James Rhoads	Arizona State University	1991
Dr. Keith Rosema	Blue Operations, LLC	1991
Dr. Shoko Sakai	UCLA	1991
Dr. Jose F. Salgado	Adler Planetarium, Chicago	1995
Dr. Nestor Aponte	Arecibo Observatory	1992
Ms. Heather Elliott	Michigan State University	1992
Mr. Adam Trotter	Univ. of North Carolina, Chapel Hill	1992
Dr. Lorraine Allen	US Coast Guard Academy	1992
Mr. Jason Johnson	Harvard University	1992
Ms. Vanessa Galarza	New Mexico State	1992
Ms. Erin Hatch	George Washington University	1992
Mr. Antonio Algaze	Ohio State University	1993
Mr. James Anderson	US Geological Survey	1993
Mr. Yevgeniy Dorfman	MIT	1993
Dr. Mayra Lebrón Santos	Univ. of Puerto Rico-Rio Piedras	1993
Dr. Ben R. Oppenheimer	American Museum of Natural History	1993
Dr. Alison Peck	ALMA, Chile	1993
Dr. Christopher DeVries	Cal State Univ., Stanislaus	1994
Mr. Mark Lemon	Letter Press Software	1994
Ms. Rebecca Morley	Japan	1994
Dr. Marcel Agueros	Columbia University	1995
Dr. Ann Bragg	Marietta College	1995
Dr. Genene Fisher	American Meteorological Society	1995
Dr. Nicole Lloyd-Ronning	Los Alamos National Labs	1995
Ms. Kristin Nelson	University of Rochester	1995
Ms. YuLing Su	Steward Observatory	1995
Mr. Matthew Schwartz	Princeton University	1996
Mr. Brent W. Grime	US Air Force	1997
Dr. Zoe M. Leinhardt	University of Cambridge	1997
Ms. Melissa Nysewander	Univ. of North Carolina, Chapel Hill	1997
Mr. Albin Alonso Rosario	University of Puerto Rico	1997
Dr. Anil C. Seth	Harvard-Smithsonian CfA	1997
Mr. Angel Alejandro Quinones	University of Houston	1998
Dr. Monique Aller	University of South Carolina	1998
Ms. Yira Cordero Lebron	UPR Humacao	1998
Ms. Ingrid Daubar	University of Arizona	1998
Mr. Simon DeDeo	Princeton University	1998
Dr. David Kaplan	Univ. of Wisconsin-Milwaukee	1998
Mr. Dale Kocevski	University of Hawaii	1998

Ms. Myriam Lopez	Escuela Intermedia Barahona, Morovis	1998
Mr. Benjamin D. Oppenheimer	University of Arizona	1998
Mr. Felix Mercado Cortes	UPR Río Piedras	1998
Ms. Celia Salmeron	University of Houston	1998
Ms. Heidi Brandenburg	Caltech	1999
Mr. Carlos Vargas Alvarez	University of Wyoming	1999
Mr. Shawn M. Allison	Penn State	2000
Ms. Sarah Boswell	University of Wisconsin	2000
Dr. Alyson Brooks	Caltech	2000
Ms. Diane Chin	Binghamton University	2000
Dr. Laura J. Hainline	US Naval Academy	2000
Mr. Justin B. Kinney	Cornell University	2000
Dr. Ruth Murray-Clay	Harvard-Smithsonian CfA	2000
Mr. Homero Cersosimo	UPR Humacao	2000
Mr. Miguel F. Irizarry	Arecibo Observatory	2000
Dr. Karin Menendez-Delmestre	Carnegie Observatories	2000
Ms. Sun Mi Chung	Wesleyan University	2001
Mr. Daniel Dougherty	University of Alabama	2001
Ms. Lindsay DeRemer	Wellesley College	2001
Ms. Natalia Figueroa	UPR Mayaguez	2001
Mr. Marko Krco	Cornell University	2001
Dr. Mike Nicolls	SRI International	2001
Ms. Betzaida Ortiz	University of Puerto Rico	2001
Ms. Val Phillips	University of Colorado	2001
Ms. Karin Sandstrom	UC Berkeley	2001
Ms. Ivelisse Cabrera	Johns Hopkins University	2001
Mr. Homero Cersosimo	UPR Humacao	2001
Mr. Mike Eydenberg	New Mexico Tech	2001
Mr. Derek Kopon	Cornell University	2001
Ms. Esther Santos	UPR Mayaguez	2001
Mr. Carlos Vargas Alvarez	UPR Mayaguez	2002
Dr. Martha Boyer	University of Minnesota	2002
Ms. Laura Chomiuk	Univ. Wisconsin-Madison	2002
Mr. Jose Gerena	Luis Munoz Marin Public School	2002
Dr. Andrew Helton	Univ. Minnesota-Twin Cities	2002
Mr. Chi-Feng (Daniel) Kao	Penn State	2002
Ms. Stephanie Morris	University of Chicago	2002
Ms. Danielle Moser	Univ. of Illinois, Urbana-Champaign	2002
Mr. Martin Rodgers	Miami University, Ohio	2002
Ms. Rebecca Wilcox	University of Washington	2002
Dr. Julia Deneva	Arecibo Observatory	2002
Ms. Ingrid Pla Rodriguez	UPR Mayaguez	2002
Ms. Samantha Stevenson	Wesleyan University	2002
Mr. Graham Alvey	University of Illinois, Urbana-Champaign	2003
Ms. Jaqueline Hodge	UC Davis	2003
Mr. Adam Mott	Arizona State University	2003
Dr. Catherine Neish	Johns Hopkins University	2003
Mr. Matthew Phillips	University of Colorado	2003
Mr. Kristopher Reilly (deceased)	New College of Florida	2003
Ms. Elizabeth Schmidt	Carthage College	2003
Ms. Coral Wheeler	University of Akron	2003
Ms. Nerlyn Echevarría	UPR Mayagüez	2003
Mr. Carlos Trinidad	Daskalos Middle School	2003

Dr. Romina Nikoukar	University of Illinois, Urbana-Champaign	2003
Mr. Michael Jouteux	Ecole Normale Superieure, Lyon, France	2003
Ms. Megan DeCesar	Pennsylvania State University	2004
Ms. Laura Kinnaman	Wittenberg University	2004
Ms. Melissa Rice	Cornell University	2004
Mr. Karles Saucedo-McQuade	Oberlin College	2004
Mr. Drew Turner	Embry-Riddle Aeronautical	2004
Mr. Jan Ulrich	University of Texas-Austin	2004
Ms. Yang Yang	Miami University	2004
Mr. Harus J. Zahid	University of California-Berkeley	2004
Mr. Jose Casillas	UPR Mayagüez	2004
Ms. Regina Flores	Columbia University	2004
Ms. Giselle Miranda	Wesleyan College	2004
Mr. Evan J. Anzalone	Louisiana State University	2005
Ms. Fonda Day	University of Colorado	2005
Mr. Casey Dreier	Oberlin College	2005
Ms. Igneris Franco	UPR Mayagüez	2005
Ms. Rhea C. George	University of California, Berkeley	2005
Mr. Israel Gonzalez Perez	UPR Mayagüez	2005
Ms. Talia Kohen	Cornell University	2005
Ms. Laura Kushner	University of Washington	2005
Mr. Iain Mansfield	Cambridge University	2005
Mr. Alex J. Rivera Irizarry	UPR Mayagüez	2005
Mr. Anthony Salvagno	SUNY-Albany	2005
Ms. Sarah Scoles	Agnes Scott College	2005
Mr. Brandon Taylor	University of Texas, Austin	2006
Mr. Clinton Mielke	University of Arizona, Tuscon	2006
Mr. Daniel Rucker	University of Arkansas, Little Rock	2006
Mr. David Bowen	Cornell University	2006
Ms. Heather Hanson	University of Wyoming	2006
Ms. Heidi Brooks	Reed College	2006
Ms. Isobel Ojalvo	Rensselaer Polytechnic Institute, NY	2006
Mr. Kevin Graf	Cornell University	2006
Ms. Knicole Colon	College of New Jersey	2006
Ms. Sonia Buckley	Trinity College Dublin, Ireland	2006
Ms. Ximena Fernandez	Dartmouth College	2006
Ms. Mellisa Rivera	UPR Mayaguez	2006
Mr. Edvier Cabassa	UPR Mayaguez	2006
Mr. Israel Gonzalez	UPR Mayaguez	2006
Ms. Gloria Isidro	UPR Rio Piedras	2006
Ms. Megan Ansdell	University of St. Andrews, Scotland	2007
Mr. John Barrett	University of Massachusetts, Amherst	2007
Mr. Charles Cheung	Cornell University	2007
Mr. Jamie Gardner	McGill University, Canada	2007
Ms. Diana Husmann	Massachusetts Institute of Technology	2007
Ms. Rouwenna Lamm	Smith College	2007
Mr. John Lee	Columbia University	2007
Ms. Amanda Sheffield	Purdue University	2007
Ms. Camille Smith	Utah State University	2007
Mr. Matthew Sunderland	Penn State University	2007
Ms. Catherine Wu	New Mexico State University, Las Cruces	2007
Mr. Ali Amirrezvani	City College of NY	2008
Mr. Ethan Engle	Case Western Reserve University	2008

Ms. Diana Prado	UPR Mayaguez	2008
Ms. Darlene M.Nieves	Interamerican in Bayamon	2008
Mr. Elvin Vega-Vega	Interamerican in Bayamon	2008
Mr. Anthony Allen Smith	University of Missouri in Columbia	2008
Ms. Tracy Becker	Lehigh University	2008
Ms. Kristin Jones	University of Wisconsin-Madison	2008
Mr. Victoir Veibell	Embry-Riddle Aeronautical School	2009
Ms. Danna N. Qasim	Northern Arizona University	2009
Mr. Alexander L. Hackett	Penn State University	2009
Ms. Yaritza de Jesus Arce	UPR Mayaguez	2009
Ms. Diana C. Centeno	UPR Humacao	2009
Ms. Ali Bramson	University of Wisconsin at Madison	2009
Ms. Aleshka Carrion Matta	UPR Rio Piedras	2009
Mr. Eframir Franco Diaz	Petra Mercado Bougart High School	2009
Mr. Edvier Cabassa	UPR, Mayaguez	2009
Mr. Alex Macomber	University of Notre Dame	2009
Ms. Cristina Padilla Cintron	UPR Rio Piedras	2009
Mr. Christopher Faesi	Indiana University	2009
Ms. Daria Auerswald	San Diego State University	2009
Mr. José I. López Pérez	UPR, Rio Piedras	2009
Ms. Melissa Rivera	UPR, Mayaguez	2009
Ms. Isaira Rodriguez (RET)	Arecibo Public School System	2009
Mr. Scott Barenfeld	University of Rochester	2010
Mr. Thomas R. Devine	Fairmont State University	2010
Mr. Derek S. Felli	Brigham Young University	2010
Mr. Brandon T. Fetroe	Stanford University	2010
Mr. David Gonzalez Alcantara	UPR Mayaguez	2010
Mr. Nicholas J. Jimenez	Alfred University	2010
Ms. Deborah R. Schmidt	Franklin & Marshall College	2010
Mr. Timothy M. Taber	Vassar College	2010
Ms. Chelsea L. M. Vincent	University of Pittsburgh	2010
Mr. Jayanth Chennamangalam	West Virginia University	2010
Ms. Emy Rivera	UPR Rio Piedras	2010
Ms. Kethy Trujillo	Arecibo School District	2010