

**NATIONAL ASTRONOMY AND IONOSPHERE CENTER**  
**ARECIBO OBSERVATORY**  
*Cornell University*

**Research Experience for Undergraduates Program**

**PROGRESS REPORT**  
**SUMMER 2006**

(Written by Dr. Shikha Raizada, REU Coordinator)

The Arecibo Observatory organized its 2006 REU summer student program for 10 weeks from the end of May to mid August. This program exposes students to various activities with the aim of motivating them to pursue their future career in research. The selection process is highly competitive with 11 students getting selected from different universities out of nearly 115 applicants. These eleven students were funded from different sources, (a) eight were supported by the NSF REU grant, (b) two recent graduates supported by NAIC, and (c) one was selected on the basis of the Observatory Director's discretion. In addition, (a) three students from UPR/Mayagüez worked at the Observatory and were funded by the Partnership for Space Science Education and Research (PaSSER) program, and (b) one was supported by '*Fundacion Comunitaria de Puerto Rico*' and worked on a project related to education and outreach activity to promote science for the disabled. Apart from this, there were two graduate students from Colorado Research Associates (CoRA), working with their Ph.D. supervisor Dr. Diego Janches, who used the facilities at the Observatory for their research work, which will eventually lead to their Ph.D. theses. These students, Amal Chandran and Jonathan Fenzke, participated in the REU activities and also gave 20-minute presentations towards the end of the program. One of the highlights of this year's program was the participation of students from U.S. universities, and two from outside the U.S. One student (Sonia Buckley) attends college in the Republic of Ireland and one (Ximena Fernandez) is originally from Colombia, which allowed students from diverse backgrounds to interact.

Professors Julio Urbina (Penn State University) and José Rosado (UPR/Mayagüez) visited the Observatory this summer and mentored a few REU students. Also, Prof. Carmen Pantoja (UPR/Rio Pedras) and her student spent a month working at the Observatory's Visitor Center to develop techniques for promoting science among the vision and hearing impaired. Several Observatory staff members gave lectures to the students with the objective of introducing them to the fundamentals and applications of the various instruments available on site. The talks included a variety of topics covering areas related to astronomy, ionospheric science, planetary radar, and electronics with focus on the current research activities using the facilities at the Observatory. This was complemented with a visit to the 500-ft high platform that contains several receivers. The engineers and technical staff showed them the 430 MHz transmitters, which was beneficial to the engineering students. A very distinguished visitor, Dr. Jocelyn Bell, was invited to the Observatory as the 2006 William E. and Elva F. Gordon Distinguished Lecturer. During her visit, she gave a popular lecture on "Reflections on the Discovery of Pulsars" on 27 June 2006. A get-together was arranged that allowed female students to interact with her and gave them excellent opportunity to discuss issues related to women in science. Also, several visitors to the Observatory gave talks that were attended by the REU students. This list includes: D. Campbell, P. Taylor, Eliana Nossa (Cornell University), X. Chu (Colorado State University), G. Cortés (NAIC, Cornell), D. Werthimer (UC Berkeley), and J.C. Morales (Turabo University).

The research experience for REU students comprised a mandatory project (individual) and an optional project (group of 3 to 4 students) as a part of a hands-on experiment. The mandatory project involved either real time observations or previously obtained data and their analysis/interpretation. Those who wanted to obtain experience on the procedures related to observing were offered participation in hands-on experiments that were conducted by Arecibo staff members, Drs. Mayra Lebron, Chris Salter and Tapasi Ghosh. Three runs were scheduled that provided students an excellent opportunity to get their 'hands dirty'. A summary of the hands-on experiments is provided later in this document.

The students were asked to give 20-minute presentations summarizing the project they worked on during their stay at the Observatory. Some of the students will present their work in meetings/conferences. The aeronomy students plan to participate in the CEDAR (Coupling, Energetics and Dynamics of Atmospheric Regions) in June 2007. Similarly, the astronomy students will present posters at the meetings of the American Astronomical Society in October 2006 and January 2007. It is worth mentioning that one of the students (Ms. X. Fernandez) who worked with T. Ghosh, C.S. Salter and E. Momijan discovered a new galaxy and has expressed her interest in participating in follow-up work and to pursue astronomy as her future career.

There is a famous saying that 'All work and no play makes Jack a dull boy'. To make sure that students get a chance to experience life outside the Observatory, a variety of activities were arranged that gave them an opportunity to explore the culture and nature of the Caribbean island. Many thanks to all the administrative staff, especially Maria Rodriguez, Lucy Lopez, Wilson Arias, Carmen Segarra, Carmen Torres, Eva Robles, José Cordero, and all the drivers for their cooperation and time. As a welcome to students, a BBQ was organized near the recreational area. We encouraged students to give us feedback about their interests and tried to organize events accordingly. Some students became certified for scuba diving and then visited places like the Mona and Vieques Islands that are famous for their beautiful beaches and sea life. This gave them a chance to camp, hike and snorkel in different locations. The students spent a weekend camping in the El Yunque Rain Forest. Also, a cultural trip to Old San Juan was arranged that was coupled with a visit to the Bacardi factory that is famous for manufacturing the most popular rum in the world. There was an educational trip to the Institute of Tropical Ecosystem Studies located in the Rain Forest, which also hosts REU students and is coordinated by Dr. Alonso Ramirez and was later reciprocated by a visit to the Observatory. A trip to a cultural festival in the nearby town of Hatillo was organized that exposed students to the local music, dance and food. On many occasions, students were accompanied by other staff members (P. Freire, J. Wiig, P. Guitreas, and H. Vo) to several beaches and other scenic spots. We also took them out to watch recent movies and to dance establishments. Toward the end of the summer, another BBQ was arranged to welcome the Rain Forest REU students and also to give a farewell to our own students. The two groups played volleyball and exchanged their experiences. On several occasions, the students organized evening get-togethers at the VSQ and invited staff members and vice-versa.

## 2006 Summer Student Projects

### *Supported by NSF REU Funds:*

**Heidi Brooks** is currently a senior at *Reed College*. As an REU student, she worked with Dr. Ellen Howell and studied the orbits of binary asteroids in the near-earth population as a means for obtaining measurements of their densities. She worked primarily with radar-obtained delay Doppler images of 2003 YT1, 2002 BM26, and 2006 GY2. She recorded the range separation of the primary and secondary asteroids at various time intervals, as well as their respective bandwidths. The values obtained for range separation were plotted versus time and fitted to sine curves, as would result from the (assumed) circular orbits of the secondaries. They were found to exhibit the following periods: 2003 YT1,  $36.7 \pm 1.8$  hours; 2002 BM26, either  $12.5 \pm 0.2$  or  $25.8 \pm 0.3$ ; and 2006 GY2,  $11.7 \pm 0.2$  hours. Additional data for YT1 along with the use of a modeling program called Shape allowed constraints to be placed on the geometry of the system. From these inputs, Heidi was able to calculate the mass and volume of the primary to be  $(1.27 \pm 0.39) \times 10^{12}$  kg and  $0.63 \pm 0.10$  km<sup>3</sup>, respectively, resulting in a final estimate of the density to be  $2.01 \pm 0.70$  g/cm<sup>3</sup>.

**Sonia Buckley** is a first-year undergraduate student at *Trinity College Dublin, Ireland*, studying Natural Sciences. She worked with Johannes Wiig to calibrate the Pennsylvania State University all-sky imager. The all-sky imager is a sensitive digital camera that collects images of the entire night sky for the purpose of studying airglow events. Sonia's project involved the intensity calibration and flat-fielding of the imager. To do this, many images had to be taken of a light source of known intensity under different conditions. The imager

was dismantled from its position in the airglow laboratory and set up underneath a C14 calibration source. The calibration data was collected over the course of several nights to avoid light contamination. Sonia then used IDL to analyze these results and carry out the calibration. The program `doframe.pro` for automatically flat-fielding and converting pixel counts to intensity values of any image taken with the camera was created using the results of the calibration. All the results and IDL programs will be posted on the web at <http://allsky.ee.psu.edu> along with the images taken every night with the all-sky imager so that anyone can access the data. This means that the calibration data will be used when studying the images to obtain more accurate, understandable images.

**Knicole Colón** is a senior at the *College of New Jersey*. She worked with Dr. Mayra Lebrón on reducing and analyzing the 18 cm (1665, 1667, 1612, and 1720 MHz), 6 cm (4765, 4751, and 4660 MHz) and 5 cm (6031, 6035, 6049, and 6017 MHz) OH lines, as well as the 4830 MHz H<sub>2</sub>CO and the 6668 MHz CH<sub>3</sub>OH lines, all arising in the massive star-forming region IRAS 19111+1048. All lines were observed on July 4-5, 2005 using the Arecibo Telescope L-band, C-band and C-high receivers. The analysis was completed using Arecibo routines for reducing correlator data. Maser emission was confirmed in the 1665, 1667, 6031, and 6035 MHz OH lines, and each maser line was accompanied by an absorption feature. By comparison with previous studies, all but the 6031 MHz line appear to be highly variable. The 6 cm OH lines, the 18 cm (ground-state) and 5 cm (excited-state) OH satellite lines, and the absorption features in the four masing lines were found to exhibit weak and broad spectral profiles located at velocities slightly higher than that of the source, indicating that their appearance may be due to a form of quasi-thermal excitation rather than the masing process. Currently there is no evidence for either H<sub>2</sub>O or CH<sub>3</sub>OH masers, but massive CO outflows have been detected through previous studies. Along with the detection of OH masers, these properties place IRAS 19111+1048 in a late stage of protostellar evolution in which the H II region has expanded and developed enough to allow for conditions that are unable to generate H<sub>2</sub>O or CH<sub>3</sub>OH masers. As a separate result, the near and far kinematical distances to this source were determined to be, respectively, 4.4 and 7.6 kpc.

**Kevin Graf** is a senior at *Cornell University* and worked with Ganesh Rajagopalan. His work focused on the C-High Receiver at the Observatory that is mostly used for 6.7 GHz Methanol Maser line surveys. However, there is interest in upgrading the receiver to a dual-beam receiver for continuum observations. The receiver possesses two feed horns and two front-end receiver chains. The planned implementation of Dicke-switching at rates of approximately 10 Hz following the dewar should nullify the 1/f-noise from fluctuating atmospheric emissions. The type WBA13 MMIC amplifiers used at the C-High Receiver front-end, however, possesses Heterojunction-FETs, which are known for possessing 1/f-noise that can limit the sensitivity of continuum observations. Using the test setups assembled and verified this summer, the stability of the type WBA13 MMIC amplifiers, as well as of the C-High Receiver as a whole, will be characterized. The Allan Variance of the samples should offer recommended integration times and switching rates. These results should guide the process of the dual-beam upgrade as well as provide useful information to observers who use the receiver for continuum observations.

**Heather Hanson** is a senior at the *University of Wyoming*. She worked with Dr. Mike Nolan and her project focused on the asteroid 105 Artemis, which is a C-type main-belt asteroid that has been observed to contain hydrated minerals on at least a portion of its surface. Seventy-five percent of all asteroids belong to the C-type classification. These asteroids are often observed to have absorption bands near 0.7 microns and 3.0 microns. The 0.7-micron absorption feature indicates the presence of iron bearing phyllosilicates that are related to hydrated minerals, while the broad 3.0 micron absorption is caused by overlapping absorption bands from H<sub>2</sub>O and OH layers in hydrated minerals. Often, the 0.7-micron band is not observed but hydrated minerals are present and absorption at 3.0 microns is seen. To further understand the link between the absence and/or presence of the different bands, radar data from the Arecibo Observatory and spectra from the IRTF on Mauna Kea have been obtained for a number of asteroids. Many of the radar data show irregular, non-symmetric bright features that may be linked to the reflectivity of the surface, and therefore the composition instead of the shape of the asteroid. Both radar observations and near-infrared spectra of 105 Artemis have been obtained and analyzed. Heather coordinated the radar and spectral data using lightcurve data obtained from the amateur astronomy community. Through a modeling program called Shape, these data were used to make a simplified 3D model of 105 Artemis in order to map the areas where hydrated minerals have been observed. Once

mapped, the link between the hydrated minerals and radar-bright areas can be tested.

**Clinton Mielke** is a senior at the *University of Arizona, Tucson*. He worked with Dr. Paulo Freire this summer, the resident pulsar expert. Paulo gave him the choice between two projects to work on, and stepping up to the challenge, he decided to undertake both. First, he worked on a numerical simulation of a particular binary pulsar system. By using the 4th order Runge Kutta algorithm, he tested the general relativistic perturbation on the pulsar's orbit, and found a precession of the periastron over a specific timescale that agreed with theoretical models. Unfortunately, the amount of drift has been found to be too small to observe, so although his code worked well, the binary system is not a strong candidate for testing General Relativity.

On his second project, he wrote an orbital fitting program that uses the Levenberg-Marquardt method to perform a least squares fit. When given an input file of epochs and periods, the algorithm finds keplerian orbital elements and a few additional parameters for the particular system in question. This program will likely become a valuable tool for astronomers in the pulsar community, as no open source alternative seems to exist for this particular application. He will be coordinating his efforts with Paulo over the upcoming few months to modify this application and bring it into use amongst all who need it.

**Isobel Ojalvo** is a senior student at *Rensselaer Polytechnic Institute* in Troy, NY studying physics and mathematics. Her REU summer project supervisors were Drs. Steven Gibson and Robert Minchin. Her REU project was to determine what is needed to put data obtained from the Arecibo L-Band Feed Array (ALFA) onto the Virtual Observatory (VO) and to implement a preliminary database and website. The VO is an international collaboration to make large astronomical surveys available to the public with a suite of search and intercomparison tools. Ojalvo's focus was on the VO interface for ALFA surveys of the Galactic interstellar medium (GALFA) and HI environments around other galaxies (AGES), both of which are generating large, 3-dimensional data sets. She used the scripting language Perl as a common gateway interface to access the data and investigated how to provide a web-interface that will allow users outside the Observatory to extract subsets of the data via the World Wide Web.

**Daniel Rucker** is a fourth-year undergraduate student at *University of Arkansas at Little Rock*, majoring in Systems Engineering. He worked under the supervision of Prof. Julio Urbina and Ryan Seal on the development and implementation of an FPGA-based radar controller for the Space and Atmospheric Sciences Group at the Arecibo Observatory. This device will be integrated with the recently developed multi-channel digital receiver acquisition system to conduct radar observations. The radar controller will provide up to 16 control signals: sample start trigger to the receiver board, T/R switching, RF pulse, blanking, coding, etc. It will also control two 8-bit digital-to-analog converters (DACs) for multi-frequency signal generation. The device is an external module that is programmed via the USB 2.0 port and offers a total of 50 I/O pins. Configuration and operation of the device is achieved with a general-purpose computer through a graphical interface under Linux OS.

### ***Supported by NAIC funds:***

**David Bowen** graduated from *Cornell University* in May 2006. This summer he worked with Ganesh Rajagopalan on a project related to signal interference. Broadband signal information is vital to identifying and diagnosing signal interference in radio astronomy and radar experiments at the Arecibo Observatory. Previously, data available remotely is band limited and does not reveal effects of system problems and RFI from sources such as lightning. Data from an instrument capable of displaying the broadband signal needs to be available to remote users at the time of their experiments. These remote users include engineers in their homes in the Arecibo area as well as scientists in arbitrary locations around the world.

Using an Agilent E4403B ESA-L series spectrum analyzer, broadband signal information must be made available. Since the data must reach potentially around the world, the data must be available through an internet gateway, or web server. Two solutions were implemented: LabVIEW programs using the web publishing utility

and a Java client/server program pair. LabVIEW was more easily implemented, but required the overhead of a runtime engine to be interactive (called *embedded mode*). At the cost of refresh rate, LabVIEW web publishing could exist in a *monitoring mode* that does not require a runtime engine. Both methods were implemented and are available. The Java client/server pair was also implemented. Java would not require a runtime engine and offers a high refresh rate, at the cost of more difficult implementation and more difficult future upgrades and modifications. Given a stable Java client/server pair, the Java version would be better for scientists who won't have the LabVIEW runtime engine.

**Maria Ximena Fernandez** is a senior currently enrolled in a dual degree program, where she studies Physics and Astronomy at Vassar College and Engineering Sciences at *Dartmouth College*. At the Observatory, she worked with Drs. Tapasi Ghosh, Emmanuel Momjian, and Chris Salter analyzing HI 21 cm and OH 18 cm spectral line observations of a group of luminous infrared galaxies (LIRGs). These galaxies emit most of their energy at infrared wavelengths and are found in interacting/merging systems. The intense infrared luminosity ( $L_{\text{ir}} > 10^{11} L_{\odot}$ ) is due to the dust heating from extreme starburst and/or active galactic nuclei energy sources. In 2004, Arecibo observations were made using the L-Band Wide receiver of 85 LIRGs from the 2 Jy IRAS-NVSS sample. The sample was observed with ON/OFF or double position switching (DPS) modes, depending on the radio continuum flux density of the target sources, and the data were reduced with IDL. The team detected HI in 82 galaxies (16 new detections), and OH in 7 galaxies (5 new detections). In some cases, the HI spectra showed the classic Gaussian or double horn distributions, while the majority exhibited distorted features indicating that they are in an interacting/merging system. IRAS 23327+2913 is considered to be the most intriguing source in the sample. This ultra-luminous infrared galaxy (ULIRG,  $L_{\text{ir}} > 10^{12} L_{\odot}$ ), which is described in the literature as a pair of nuclei in the beginning stages of interaction was detected in both neutral hydrogen and OH megamaser emission from the system, which had not been reported before. The OH spectrum of this galaxy is complex and composed of multiple peaks.

**Brandon Taylor** graduated from the *University of Texas at Austin* this past May with a degree in Electrical Engineering. While there, he worked in ionospheric research at the Applied Research Laboratories. Prior to coming to the Arecibo Observatory, he also spent a summer as an REU student at the MIT Haystack Observatory.

This summer, he worked with Dr. Hien Vo on a project to statistically analyze Subauroral Polarization Streams (SAPS). SAPS, which can be detected by elevated ion drifts equatorward of the auroral oval, are associated with disturbed ionospheric conditions. A better understanding of these events can improve ionospheric models and reduce errors in GPS and other satellite communications.

Brandon's project was aimed at exploiting the continuous data collection of DMSP satellites to provide a better statistical analysis of SAPS than had previously been performed. He developed an algorithm to automatically process a year's worth of satellite data and to detect and quantify high ion drifts as SAPS. Additional code was written to compare various properties of these SAPS in a variety of geomagnetic conditions. In addition to the results achieved this summer, the project will be extended by Dr. Vo.

***Supported by PaSSER funds:***

**Edvier Cabassa-Miranda**, a sophomore at *The University of Puerto Rico-Mayagüez*, worked with Prof. Julio Urbina (Visiting Scientist from Penn State) and used radar observations from the Coqui II 50 MHz radar located near Salinas, Puerto Rico, to measure observed counts of both specular and non-specular meteor trails in the E-region ionosphere. These observations were made over a time span ranging from 18:00 to 08:00 on various days in 1998 and 1999. The Coqui II radar has two sub-arrays, both pointed to the north in the magnetic meridian plane, perpendicular to the magnetic field elevation angle of approximately 41 degrees. Traditional meteor radars require trail specularity (trail perpendicular to radar beam) for a reflection, but over the last decade, two new types of radar-meteor reflections, known as meteor head echoes and non-specular trails, have become known or widely used. He attempted to see if this radar is capable of detecting the head echoes. He analyzed the

signals by removing unwanted interference using some routines that he developed in IDL. Now the future work is to try to generate RTI images to see the head echoes. He would also like to conduct simulations.

**Israel Gonzalez-Perez Jr.**, who is an undergraduate in electrical engineering at *The University of Puerto Rico at Mayagüez*, returned to Arecibo this summer to continue a project started during the previous summer under the tutelage of Dr. Jonathan Friedman. This is the construction of a test bed and calibration system for a Faraday filter. The purpose of the filter system is to take measurements of the temperature and potassium content in the mesosphere during the daytime, utilizing LiDAR technology. The test bed is composed of a tunable single-mode external cavity diode laser, the filter, a potassium vapor cell in an oven with fluorescence detection, and a Fabry-Perot etalon. The oven was constructed during the first summer using a thermal plastic housing to encase the vapor cell. Attached to the cell were two heating pads controlled by a thermistor. The controller circuit was also built during the first summer. The oven heats a potassium spectrum cell to obtain a uniform vapor distribution within it. Then, using the laser, we record the spectral emission in a “Doppler-free” configuration. Since the emission lines of the potassium are well known, it is possible to use the system to tune the Lidar and obtain a reliable wavelength scale for the filter calibration measurements.

The challenge for this past summer was to install the Fabry-Perot etalon and to detect fluorescence from the vapor cell in the “Doppler-free configuration”. Unfortunately, in the course of these measurements it was discovered that the cell did not actually contain potassium. Another cell was bought for the system. However, it was larger than the original and another oven had to be fabricated in order to use it. The work for the summer was basically the modification of the new oven and the construction of the Fabry-Perot etalon. As the summer was ending, Israel was able to get an assignment to finish the project through the University of Puerto Rico, thanks to Prof. José Rosado. Currently, Israel is working to find the fluorescence and tweak the etalon.

**Melissa Rivera** is currently an undergraduate student in Electrical Engineering at *The University of Puerto Rico at Mayagüez*, with a strong interest in Communications, Physics and Astronomy. She is also the Vice-President of the Caribbean Astronomical Society of Puerto Rico.

Her project at the Observatory focused on analysis of data from Jicamarca Observatory using its radar named JULIA (Jicamarca Unattended Long-term Investigations of the Ionosphere and Atmosphere). This study analyzed perturbations in the electric field as a result of geomagnetic substorms on equatorial latitudes. The method that she used to obtain conclusions for these phenomena is called Superposed Epoch Analysis, which is a very powerful technique. It consists of sorting data into categories and comparing means for different categories. This method must be applied carefully and logically.

The analysis of the radar data shows disturbances in the daytime equatorial geomagnetic H field associated with specific phases of isolated substorms. Three well-documented substorms were examined in India, but now with this investigation, she has found more than 102 days of perturbations at different hours and different days in 2004 and 2005. This pattern of response constitutes the first-time-evidence for the occurrence of equatorial H-field perturbations related to the growth phase as well as the expansion phase of individual substorms.

### ***Funding from Other Sources:***

**Gloria Isidro** worked at the Visitor Center under the supervision of Drs. Carmen Pantoja and José Alonso with a scholarship from the “Fundacion Comunitaria de Puerto Rico”. She is a graduate student at the Department of Mathematics at *The University of Puerto Rico-Rio Piedras*. This summer she developed a guide for the Observatory for blind visitors. The guide consists of three documents in Braille with text and high relief figures describing the parts of the telescope, important terms used in radio astronomy, and frequently asked questions. Together with Prof. Carlos La Rosa, UPR-Utuado, a tactile model of the telescope was also developed. These materials will help in making the Arecibo Observatory a more accessible facility and an Observatory for all.



Back row (left to right): Edvier Cabassa, Clinton Mielke, Daniel Rucker, Melissa Rivera.  
 Middle Row (left to right): Brandon Taylor, Heather Hanson, and David Bowen (leaning on table).  
 Front row (left to right): Dr. Shikha Raizada, Knicole Colon, Sonia Buckley, Isobel Ojalvo, and Kevin Graf (leaning on table).  
 Not shown: Heidi Brooks, Maria Ximena Fernandez, Israel Gonzalez, and Gloria Isidro.

### 2006 Staff and Visitor Talks\*

\*Speakers are Arecibo Observatory staff members unless otherwise noted.

- Jun 2 The Shape and Spin State of Near Earth Asteroid 54509 (2000 PH5) [Patrick Taylor, Cornell Univ.]
- Jun 8 Beyond ALFA, Instrumentation Development for Arecibo [German Cortés, NAIC]
- Jun 9 The Antenna Design of the Focal Phase Array [Eliana Nossa, Cornell Univ.]
- Jun 9 Arecibo Transmitters [Joe Greene]
- Jun 14 Geology of Puerto Rico [Ellen Howell]
- Jun 16 Introduction to Pulsar Astronomy [Paulo Freire]
- Jun 21 Radio Astronomy Receivers –I [Jon Hagen]
- Jun 22 Signal Processing in Radio Astronomy [Jon Hagen]
- Jun 23 The Radio Sky [Chris Salter]
- Jun 27 Reflections on the Discovery of Pulsars [Jocelyn Bell Burnell, Univ. of Oxford]
- Jun 29 Time-varying OH/IR Stars [Murray Lewis]
- Jun 29 Dynamic Properties and Seismic Response of the Cable Structure and Towers of the Arecibo Observatory [Juan Carlos Morales, Turabo University]
- Jul 6 Radio Astronomy Receivers – II [Ganesh Rajagopalan]
- Jul 7 Laser Remote Sensing Overview [Xinzhao Chu, Univ. of Colorado]
- Jul 12 Time and Coordinate Systems [Mikael Lerner]
- Jul 13 High Speed Digital Design [Tamara Hall]
- Jul 17 Active Galactic Nuclei [Tapasi Ghosh]
- Jul 17 Asteroids [Mike Nolan]
- Jul 19 The Mesospheric Refrigerator [Jonathan Friedman]
- Jul 20 GALFA and the Galactic Interstellar Medium [Steven Gibson]

- Jul 26 Introduction to Incoherent Scatter Radar – I [*Mike Sulzer*]
- Jul 27 Introduction to Incoherent Scatter Radar – II [*Mike Sulzer*]
- Aug 1 The Lunar South Pole and NASA's Lunar Exploration Initiative [*Don Campbell, Cornell Univ.*]

Apart from the above mentioned talks, there were many other talks including the Gordon Lecture during the REU program and are listed on the web page: [www.naic.edu](http://www.naic.edu)

### **Presentations by Summer Students:**

- Jul 27 Arecibo Observatory and the National Virtual Observatory [*Isobel Ojalvo*]
- Jul 31 A Study of the Massive Star-Forming Region IRAS 19111+1048 [*Knicole Colón*]
- Jul 31 Observations of Specular, Non-specular, and Head Echoes Meteors with the VHF Coqui2 Radar [*Edvier Cabassa*]
- Aug 1 Electric Field Perturbations at Equatorial Latitudes Produced by Geomagnetic Substorms [*Melissa Rivera*]
- Aug 2 Development of a FPGA Based Radar Controller [*Daniel Rucker*]
- Aug 2 Coordinated Radar and Spectral Data of 105 Artemis [*Heather Hanson*]
- Aug 3 Amplifier Stability as a Limiting Factor in Receiver Sensitivity [*Kevin Graf*]
- Aug 3 Mass Determination from Orbits of Binary Asteroids [*Heidi Brooks*]
- Aug 4 Subauroral Polarization Streams: Storm Effects and Statistics [*Brandon Taylor*]
- Aug 7 Engineering Solutions to Remote Instrument Control using LabVIEW and JAVA [*David Bowen*]
- Aug 9 Arecibo Observatory for All [*Gloria Isidro*]
- Aug 10 K Lidar Meteor Observations Using Dual Optical Receivers at the Arecibo Observatory [*Jonathan Fentzke*]
- Aug 10 Modeling the Meteoric Mass Deposition in the Upper Atmosphere [*Amal Chandran*]
- Aug 14 Numerical Applications of Pulsars - Theoretical Models, Ephemeris Determination [*Clinton Mielke*]
- Aug 15 Understanding (Ultra) Luminous Infrared Galaxies: Arecibo Observations of HI and OH Spectral Lines [*Ximena Fernandez*]
- Aug 15 Calibration of the All-sky Imager [*Sonia Buckley*]

### **Summary of Hands-on Project:**

#### **The Detection of Formaldehyde in a Molecular Cloud seen at Half the Present Age of the Universe (Supervisors: Drs. Chris Salter, Tapasi Ghosh and Mayra Lebron)**

The 2006 REU "hands-on" observing consisted of a single project designed to demonstrate the fundamentals of measuring spectral lines from extragalactic interstellar molecules with the Arecibo 305-m telescope. In particular, the observations at frequencies above 4 GHz were made in the standard ON/OFF mode, while below this frequency Double Position Switching (DPS) was used to eliminate the standing waves resulting from the continuum emission within the field.

The target radio source, B0218+357, is a strong compact continuum emitter. It is an active galactic nucleus (AGN) with a redshift of  $z = 0.944$ , and thought to be a BL Lac object. It is also one of the most compact gravitational lens systems yet known, (image separation = 0.334 arcsec). It has a complex distribution of emission, with two dominating compact sources and an Einstein ring. Absorption of the continuum emission from the AGN by the lensing galaxy, a face-on spiral of type Sa/Sab, is seen at  $z = 0.68466$ , (a) optically, (b) for the 21-cm HI radio line, and (c) for a number of radio- and mm-wave molecular lines. However, absorption is only seen against the stronger of the compact components. Detected molecular species to date are CO, HCN,

HCO<sup>+</sup>, H<sub>2</sub>CO (4.829- & 14.488-GHz transitions), H<sub>2</sub>O, CS, OH (1.665- and 1.667-GHz transitions), and possibly LiH. Detections of molecular lines at such high redshift are highly unusual, and can throw much light on the nature of the cloud that is absorbing the emission from the background AGN/BL Lac object. The look-back time to the lensing galaxy/absorbing cloud is about half a Hubble time!

The present project used the 305-m telescope to look for selected molecular absorption lines in the spectrum of B0218+357. It attempted confirmation of the two previously detected H<sub>2</sub>CO (formaldehyde) lines, and searched for absorption from a number of molecular transitions not yet detected in the absorbing cloud. Target lines and their rest frequencies were:

OH (4.66, 4.75 & 4.77 GHz; 6.02, 6.03, and 6.05 GHz)

H<sub>2</sub>C<sup>12</sup>O (4.83 GHz; 14.49 GHz)

H<sub>2</sub>C<sup>13</sup>O (13.78 GHz)

H<sub>2</sub>CS (6.28 GHz)

CH<sub>3</sub>CHO (6.39 GHz; 6.67 GHz)

HC<sub>3</sub>N (9.10 GHz)

Three 1-hour observing slots were dedicated to the project, with 8 summer students participating in these. The students performed the observations themselves, and made a first reduction of the data.

The observations confirmed the detection of both the above formaldehyde (H<sub>2</sub>C<sup>12</sup>O) absorption lines in the spectrum of B0218+357, and provided excellent signal-to-noise and velocity resolution. The lines were resolved in velocity and showed asymmetric structure. These measurements provide the excitation and column density of H<sub>2</sub>C<sup>12</sup>O, giving estimates that can be combined with results from the measurements of other detected molecular transitions.

In addition, relatively deep upper limits have been placed on any absorption from the H<sub>2</sub>C<sup>13</sup>O isotope, the excited-OH transitions, and the H<sub>3</sub>CS, CH<sub>3</sub>HO and HC<sub>3</sub>N molecular transitions.

The experiment turned out to also be a useful technical exercise. It revealed; 1) an error in the setting of heliocentric velocities for DPS measurements made with the "interim" correlator spectrometer, and 2) a short-coming in setting up for the simultaneous observation of spectral-line frequencies whose rest frequencies are separated by more than 1 GHz, but whose observed frequencies lie within a 1-GHz band due to the effects of redshift.

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### ***Students Experience in Their Own Words:***

David Bowen: *It was a fun summer. The accommodations were nice, and were better than my accommodations at NASA the previous summer in which we didn't even have access to a kitchen. It was frustrating to be stranded at the observatory most of the time, especially with nothing in walking distance. Had it not been for the stir-crazy efforts of my fellow students, it would have been more frustrating.*

Ximena Fernandez: *I just want to let you know that I really had a wonderful time, both academically and socially. Arecibo is a great place and I would love to come back at some point. I really enjoyed my project and working with my advisors (I had 3!!), and I'm planning to continue working on this as my senior thesis.*

Clinton Mielke: *I was originally very doubtful of applying to this program, for I never felt myself to be a good candidate, however the experience has shown me that I can accomplish anything if I only put my mind to it. This summer has been by far the most wonderful experience in my life. It has followed a year at my university that was very stressful for me, and has thus given me the opportunity to rediscover my passions and direction in life. I think that if I had not been given the opportunity to come here this summer, that I very well would have discontinued my undergraduate career. Furthermore, the amount that I learned over just 10 short weeks has*

*shown me that with a handful of wonderful teachers, I can learn more than I could imagine.*

Daniel Rucker: *I had a great experience this summer in Puerto Rico. The Arecibo Observatory provided me with hands on engineering experience in a unique location. Puerto Rico was a great place for a summer program. With activities like scuba diving at Mona Island, this summer was an unforgettable experience.*

***Extracurricular Activities:***

Shopping Trips for groceries, etc. (Every Monday and Thursday)  
Trip to Old San Juan/Bacardi factory; tour/beach in Isabella (10 June)  
Trip to Vieques (weekend camping 24 - 25 June)  
Welcome BBQ near the pool (16 June)  
Tango dancing (June 30)  
Trip to River behind Observatory (July 9)  
Trip to Old San Juan (July 8)  
Camping trip to El Yunque (July 15)  
Trip to the Institute for Tropical Studies in El Yunque (July 21)  
Trip to Mona Island: (July 23-25)  
Trip to Camuy Caves and Dos Bocas Lake (July 2)  
Farewell BBQ at Pool (July 18)

**Papers to be presented at meetings/conferences:**

**H. Brooks**, M. Nolan and E. Howell, *Orbits of Binary Near-Earth Asteroids from Radar Observations*, to be presented at 209<sup>th</sup> AAS meeting (Jan 6-10, 2007).

**K. Colón** and M. Lebron, *OH studies of the massive star-forming region IRAS 19111+ 1048*, To be presented at 209<sup>th</sup> AAS meeting (Jan 6-10, 2007).

**M.X. Fernandez**, E. Momjian, T. Ghosh, and C. S. Salter, *A Radio Spectral Line Study of the 2-Jy IRAS-NVSS Sample*, to be presented at 209<sup>th</sup> AAS meeting (Jan 6-10, 2007).

**H. M. Hanson**, E. S. Howell, C. Magri, M. C. Nolan, *Correlating IRTF spectral data and Arecibo radar observations of main-belt asteroid 105 Artemis*, to be presented at 209<sup>th</sup> AAS meeting (Jan 6-10, 2007).

E. S. Howell, C. Magri, **H. M. Hanson**, M. C. Nolan, *Correlating IRTF spectral data and Arecibo radar observations of low-albedo main-belt asteroids*, presented at the AAS/DPS meeting (October 9-13, 2006).

I. Ojalvo, S. Gibson, and R. Minchin, *Arecibo Observatory and the National Virtual Observatory*, to be presented at 209<sup>th</sup> AAS meeting (Jan 6-10, 2007).

**REU, Other Summer Students & RET Participants**  
(1972 through 2006)

Undergraduate Level Participants	250
Graduate Level Participants	63
Minorities	66
Women	132
(4 minorities, 8 women in 2006)	
<i>RET Participants since 1998:</i>	
Teachers	8
<b>Total Number of Participants</b>	<b>321</b>

**Number of REU, Other Summer Students & RET Participants - Scientific Field**  
(1972 through 2006)

Radio/Radar Astronomy	193
Atmospheric Sciences	82
Computer Sciences	21
Electronics	15
Education	10
<b>Total Number of Participants</b>	<b>321</b>

**Educational Institutions Represented in the NAIC Summer Student Program**  
(1972 through 2006)

Agnes Scott College	Massachusetts Institute of Technology
University of Akron	McGill University, Canada
University of Alabama	Universidad Metropolitana, San Juan
Amherst College	Miami University, Ohio
Arizona State University	University of Michigan
University of Arkansas	University of Minnesota
Bates College	University of Montana
Bethel College	Southwest Missouri State University
SUNY Binghamton	University of Nebraska-Kearney
SUNY Albany	New College of Florida
Boston University	New Mexico State University
Brigham Young University	North Carolina State University
University of British Columbia	Northwestern University
Bryn Mawr College	Oberlin College
California Institute of Technology	Oxford University, UK
California Polytechnic State University	Pennsylvania State University
University of California, Berkeley	University of Pennsylvania
University of California, Los Angeles	Pomona College
University of California, San Diego	Princeton University
University of California, Santa Cruz	University of Puerto Rico, Arecibo
Cambridge University, UK	University of Puerto Rico, Humacao
Carleton College	University of Puerto Rico, Río Piedras
Carthage College	University of Puerto Rico, Mayagüez
Case Western Reserve University	Rice University
Centenary College of Louisiana	University of Rochester
University of Chicago	Rutgers University
Clemson University	Rensselaer Polytechnic Institute, NY
Colgate University	Saddlebeck University
University of Colorado	San Diego State University
Columbia University	Smith College
Cornell University	Stanford University
Dartmouth College	Texas Technological College
Embry-Riddle Aeronautical University	Trinity College Dublin, Ireland
Ecole Normale Supérieure of Lyon	University of Texas, Austin
Georgetown University	University of Texas, Dallas
University of Georgia	University of Toronto
Gorky University, Russia	Utah State University
University of Grenoble, France	Vassar College
Harvard University	Villanova University
Haverford University	University of Virginia
University of Hawaii	Virginia Polytechnic Institute
Johns Hopkins University	University of Washington
University of Houston	Washington & Lee University
University of Illinois, Urbana-Champaign	Wellesley College
Indiana University	Wesleyan University
University of Iowa	Western Washington University
Louisiana State University	Williams College
New Mexico Tech	Wittenberg University
University of Northern Iowa	University of Wisconsin
University of Maryland	Yale University

**NAIC Summer Student Participants  
(1972 through 2006)**

Detailed information concerning the present status of all previous student or teacher participants is not available, although there are many instances where current activities are known. The following is representative of those students/teachers who have attended the NAIC's program at the Arecibo Observatory:

Participant	Current Affiliation	Summer of Participation
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	Insti. di Radioastronomie, Firenze	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 Laboratory	1982
Dr. Perry Hacking	Jet Propulsion Laboratory	1982
Dr. Brett Isham	Interamerican University of Puerto Rico	1983
Dr. Michael A. Strauss	Princeton University	1983
Dr. Douglas O. Wood	Kodak	1983
Dr. Blaise Canzian	L-3 Communications/Brashear	1984
Dr. JoAnn Eder	Arecibo Observatory (retired)	1984
Ms. Ingeborg Heyer	Joint Astronomy Centre	1984
Dr. Steven T. Myers	NRAO Socorro	1984
Dr. Joshua Roth	High school teacher	1984
Dr. Myeong-Gu Park	Kyungpook National Univ., Korea	1985
Dr. Daniel Holden	Los Alamos National Laboratory	1985
Dr. William Reach	Caltech	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/IPAC	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	Naval Research 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	AURA//Gemini Observatory	1990
Dr. Liese van Zee	University of Indiana	1990
Dr. Jeremy S. Heyl	University of British Columbia	1991
Dr. Jenny Patience	Caltech	1991
Dr. James E. 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	University of North Carolina	1992
Ms. Lorraine Allen	Center for Astrophysics	1992
Mr. Jason Johnson	Harvard University	1992
Ms. Vanessa Galarza	Museum of Science & Industry, Chicago	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	Arecibo Observatory	1993
Dr. Ben R. Oppenheimer	American Museum of Natural History	1993
Dr. Alison Peck	Center for Astrophysics	1993
Dr. Christopher DeVries	California State Univ. Stanislaus	1994
Mr. Mark Lemon	Letter Press Software	1994
Ms. Rebecca Morley	Japan	1994
Dr. Marcel Agüeros	Columbia University	1995
Ms. Ann Bragg	Bowling Green State University	1995
Dr. Genene Fisher	American Meteorological Society	1995
Ms. Nicole Lloyd-Ronning	Los Alamos National Lab	1995
Dr. Kristin Nelson		1995
Ms. YuLing (Kate) Su	Steward Observatory	1995
Mr. Matthew Schwartz	Princeton University	1996
Mr. Brent W. Grime	US Air Force	1997
Ms. Zoe M. Leinhardt	Harvard University	1997
Ms. Melissa Nysewander	Univ. of North Carolina, Chapel Hill	1997
Mr. Albin Alonso Rosario	University of Puerto Rico	1997
Dr. Anil C. Seth	Center for Astrophysics	1997
Mr. Angel Alejandro Quinones	University of Houston	1998

Ms. Monique Aller	University of Michigan	1998
Ms. Yira Cordero Lebron	UPR Humacao	1998
Ms. Ingrid Daubar	University of Arizona	1998
Mr. Simon DeDeo	Princeton University	1998
Dr. David Kaplan	MIT	1998
Dr. 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	San Diego State University	1999
Mr. Shawn M. Allison	Penn State	2000
Ms. Sarah Boswell	University of Wisconsin	2000
Ms. Alyson Brooks	University of Washington	2000
Ms. Diane Chin	Binghamton University	2000
Ms. Laura J. Hainline	Caltech	2000
Mr. Justin B. Kinney	Cornell University	2000
Ms. Ruth Murray-Clay	UC Berkeley	2000
Mr. Homero Cersosimo	UPR Humacao	2000
Mr. Miguel F. Irizarry	Arecibo Observatory	2000
Ms. Karin Menendez-Delmestre	Caltech	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	San Diego State University	2002
Ms. Martha Boyer	University of Minnesota	2002
Ms. Laura Chomiuk	University of Wisconsin	2002
Mr. Jose Gerena	Luis Munoz Marin Public School	2002
Mr. Andrew Helton	University of Minnesota	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
Ms. Julia Deneva	Cornell University	2002
Ms. Ingrid Pla Rodriguez	UPR Mayaguez	2002
Ms. Samantha Stevenson	Wesleyan University	2002
Mr. Graham Alvey	University of Illinois, Urbana-Champaign	2003

Ms. Jacqueline Hodge	UC Davis	2003
Mr. Adam Mott	Arizona State University	2003
Ms. Catherine Neish	University of British Columbia	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
Ms. 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. Ignieris 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. David Bowen	Cornell University	2006
Ms. Heidi Brooks	Reed College	2006
Ms. Sonia Buckley	Trinity College Dublin, Ireland	2006
Mr. Edvier Cabassa	UPR Mayagüez	2006
Ms. Knicole Colon	College of New Jersey	2006
Ms. Maria Ximena Fernandez	Dartmouth College	2006
Mr. Israel Gonzalez	UPR Mayagüez	2006
Mr. Kevin Graf	Cornell University	2006
Ms. Heather Hanson	University of Wyoming	2006
Ms. Gloria Isidro	UPR Rio Piedras	2006
Mr. Clinton Mielke	University of Arizona, Tucson	2006
Ms. Isobel Ojalvo	Rensselaer Polytechnic Institute, NY	2006
Ms. Melissa Rivera	UPR Mayagüez	2006
Mr. Daniel Rucker	University of Arkansas, Little Rock	2006
Mr. Brandon Taylor	University of Texas, Austin	2006