



## National Radio Astronomy Observatory REU/RET Program Report: 2008

### Overview

#### Summer Student Program

Twenty-three students participated in the 2008 NRAO Summer Student program, including 16 undergraduate students supported by the [National Science Foundation \(NSF\) Research Experiences for Undergraduates \(REU\)](#) program, three graduating senior supported by the [NRAO Undergraduate Summer Student program](#), and four graduate students supported by the [NRAO Graduate Summer Student program](#). This was the forty-ninth year of the [NRAO Summer Research Program](#), which has graduated more than one thousand students in its tenure. Research initiated in previous years by some students and their mentors continues, giving the program a continuing impact even for students who have departed.

There were 109 applicants to the 2008 NRAO summer student program, of whom 46 (42%) were women and 13 (12%) were under-represented minorities. The 16 REU positions were filled by 5 women (31%) and 11 men (69%). Of all the (23) summer students that were hired, 9 women (39%) and 14 men (61%), 1 (4%) was an under-represented minority. Eight students were assigned to Socorro (4 REU), 11 to Charlottesville (8 REU), and 4 to Green Bank (all REU).

#### Summer Teacher Program

Four teachers participated in the [2008 NRAO Research Experiences for Teachers \(RET\)](#) program funded by the [National Science Foundation](#). This was the ninth year of the NRAO RET program, which has now graduated 29 teachers. The RET program offers teachers both a research experience and, with its emphasis on carryover to the classroom, encourages inquiry-based instruction. As is for the REU students, a brief description of each RET participant's research project is included in this report. At least three and possibly all four of the teachers will present their research at the January 2009 American Astronomical Society meeting in Long Beach, CA.

There were fourteen (14) applicants to the 2008 RET program from ten states: 5 applicants (36%) were women; 9 applicants (64%) were male. The 2008 RET positions were filled by 2 women (50%) and 2 men (50%). Two teachers each were residents at Socorro and Green Bank.

## Organization of Report

This report is organized as follows. In Section 1 we list the Summer 2008 participants for both programs. We then describe the different activities in which students and teachers participated at each of the three main NRAO sites: Charlottesville (Section 2), Green Bank (Section 3), and Socorro (Section 4). In the next two sections we provide brief descriptions of the research projects completed by each REU student (Section 5) or RET teacher (Section 6). These descriptions are also available on-line at <http://www.nrao.edu/students/archive/projects.php>, which includes links to the final written reports. Lastly, in Section 7 we identify the anticipated number of participants who will present at the 213<sup>th</sup> meeting of the American Astronomical Society in Long Beach, CA (January 2009). Many of these presentations are expected to be published in astronomical journals in 2009-10.

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## 1. 2008 NRAO Summer Program Participants

This table summarizes the student and teacher participants (name and school attending), research project (title, mentor, and assigned site), and the source of student support: **NSF REU** for students supported by the [National Science Foundation \(NSF\) Research Experiences for Undergraduates \(REU\)](#) program, **NSF RET** for teachers supported by the [National Science Foundation \(NSF\) Research Experiences for Teachers \(RET\)](#) program, **NRAO GRP** for students supported by the [NRAO Graduate Summer Research Program](#), and **NRAO uGRP** for students supported by the [NRAO Undergraduate Summer Research Program](#). Overall there were 23 summer student participants (16 REU, 3 uGRP, 4 GRP) and one summer teacher (RET) participant this summer.

2008 NRAO Summer Students/Mentors (N=23)					
Student	School	Project	Mentors	Site	Program
Crystal Anderson	Western Washington University	<a href="#">X-ray emission from embedded young massive stars</a>	Debra Shepherd	Soc	<b>NRAO GRP</b>
Benjamin Breslauer	Oberlin College	<a href="#">Astronomy in the Time Domain</a>	Dale Frail	Soc	<b>NSF REU</b>
Stephanie Capen	Eastern Nazarene College	<a href="#">Infrared colors of evolved stars as a tracer of maser emission</a>	Lorant Sjouwerman & Mark Claussen	Soc	<b>NSF REU</b>

Jessica Coakley	Bridgewater College	<a href="#">The Star Formation Environment of Sharpless 106</a>	Jeff Mangum	CV	NSF REU
Claudia Cyganowski	University of Wisconsin-Madison	<a href="#">Probing the Nature of Extended Green Objects: A New Sample of Massive Protostellar Candidates</a>	Crystal Brogan	CV	NRAO GRP
Frederick Davies	New Mexico Tech	<a href="#">Relative Motions of two Massive Galaxies in the Virgo Cluster</a>	Craig Walker and Joan Wrobel	Soc	NSF REU
Kiruthika Devaraj	PSG College of Technology	<a href="#">Radio Observations and Radiative Transfer Modeling of Planetary Atmospheres</a>	Brigette Hesman & Bryan Butler	Soc	NRAO GRP
Robert Edmonds	The University of New Mexico	<a href="#">An EVLA study of H2O megamasers in submm galaxies</a>	Jeff Wagg & Chris Carilli	Soc	NRAO uGRP
Marc Eimers	University of Colorado at Boulder	<a href="#">140 Foot pulsar observation commissioning</a>	Maura McLaughlin and Dunc Lorimer	GB	NSF REU
Anthony Hamzeh	James Madison University	<a href="#">Probing the Physical and Chemical Properties of Astronomical Environments using Spectral Line Survey</a>	Tony Remijan	CV	NSF REU
Daniel Lacasse	James Madison University	<a href="#">Web Image Gallery Refactoring</a>	Pat Murphy	CV	NSF REU
Joshua Marvil	NMT	<a href="#">Understanding the nature of the microJy radio source population</a>	Frazer Owen	Soc	NRAO GRP
Stephanie Moats	New Mexico Tech	<a href="#">GBT searches for new classes of interstellar molecules</a>	Glen Langston	GB	NSF REU
Delia Mocanu	New Mexico Tech	<a href="#">Design Tool for Display of and Interaction with Large Spectral-Line GBT Data Sets</a>	Bob Garwood	CV	NRAO uGRP
Bryan Murphy	Virginia Polytechnic Institute and State University	<a href="#">Applying Semantic Web Technologies and Ontologies to the NRAO Data Vault</a>	Nicole Radziwill	CV	NSF REU
Timothy Pennucci	Columbia University, Columbia College	<a href="#">Dynamic Power Spectra: Searching for Compact Binary Pulsars</a>	Scott Ransom	CV	NRAO uGRP
Brian Sacash	Ohio Northern University	<a href="#">Data Preservation and Access for the NRAO 140ft and 12m Telescopes</a>	Ron DuPlain	CV	NSF REU
Charli Sakari	Whitman College	<a href="#">Investigating the jets of Cygnus X-3</a>	James Miller-Jones	CV	NSF REU

Alexander Savello	Emory University	<a href="#">Kinematic study of Bok globule CB4</a>	Robert Dickman	Soc	NSF REU
Matthew Schenker	Dartmouth College	<a href="#">Modeling Line Emission from Rotating Accretion Disks in AGNs</a>	Jim Braatz	CV	NSF REU
Evan Schneider	Bryn Mawr College	<a href="#">Searching for the Pulsar in SN1986J</a>	Scott Ransom	CV	NSF REU
Colin Slater	Case Western Reserve University	<a href="#">Power Spectra of HI in the Outer Galaxy</a>	Toney Minter	GB	NSF REU
Anthony Woody	West Virginia University Institute of Technology	<a href="#">A low EMI m&amp;c interface for the K band Focal Plan Array Receiver</a>	John Ford	GB	NSF REU

**2008 NRAO Summer Teachers/Mentors (N=4)**

<b>Teacher</b>	<b>School</b>	<b>Project</b>	<b>Mentors</b>	<b>Site</b>	<b>Program</b>
Jeff Paradis	Rush-Henrietta High School	Atmospheric Refraction at 1 GHz using the NRAO 43 m Telescope	Ron Maddalena	GB	NSF RET
Diana Soehl	Robert Moses Middle School	Detection of Pre-Biotic Molecules Spurs WebQuest: The Amazing Molecule Race	Glen Langston	GB	NSF RET
Sarah Streb	Salpointe Catholic High School	Pulsar Astrometry with the VLA and VLBA –and- OH Zeeman Pairs in W49 with the VLBA	Miller Goss	SO	NSF RET
Santosh Madhavan	Lake Highland Prep High School	VLA Archival Spectra of the Water Masers around the Young Stellar Object IRAS 16293-2422	Mark Claussen	SO	NSF RET



**Charlottesville Summer Students, FR, L-R, are Charli Sakari, Delia Mocanu, Evan Schneider, & Daniel Lacasse. BR, L-R, we see Jessica Coakley, Bryan Murphy, Tim Pennucci, Matt Schenker, & Brian Sacash. Not pictured are Claudia Cyganowski, Allison Hammond, & Anthony Hamzeh.**

## **2. Site Specific Activities: Charlottesville VA**

The 2008 Summer Student program at NRAO/Charlottesville was under the direction of Jeff Mangum.

There were 11 students in the 2008 Summer Student Research Program at NRAO-Charlottesville, eight of them under the NSF Research Experience for Undergraduates (NSF REU) program, one was under the NRAO Graduate Student Program (NRAO GRP), and two under the NRAO Undergraduate Summer Program. This photograph shows the 2008 Charlottesville summer students.

The summer program included a series of introductory level lectures on a wide variety of astronomical topics, often with an emphasis on radio astronomy and radio instrumentation.

The lectures are listed in the CV Summer Student Schedule below. In addition to lectures on radio astronomical science, engineering, and computing, the CV Summer Students were given a tour of the NRAO Technology

Center (NTC). The CV Summer Students also joined the GB Summer Students on a series of four research projects each of which required the development and execution of an observing plan on the Green Bank Telescope (GBT). With this always popular aspect of the CV Summer Student experience the 2008 Summer Students learned how to develop, execute, and interpret an observational radio astronomy project.

At the end of the summer, the students gave a series of 15-minute talks to the NRAO staff on their projects during several lunch symposia in Charlottesville, and produced a short report describing their summer research.

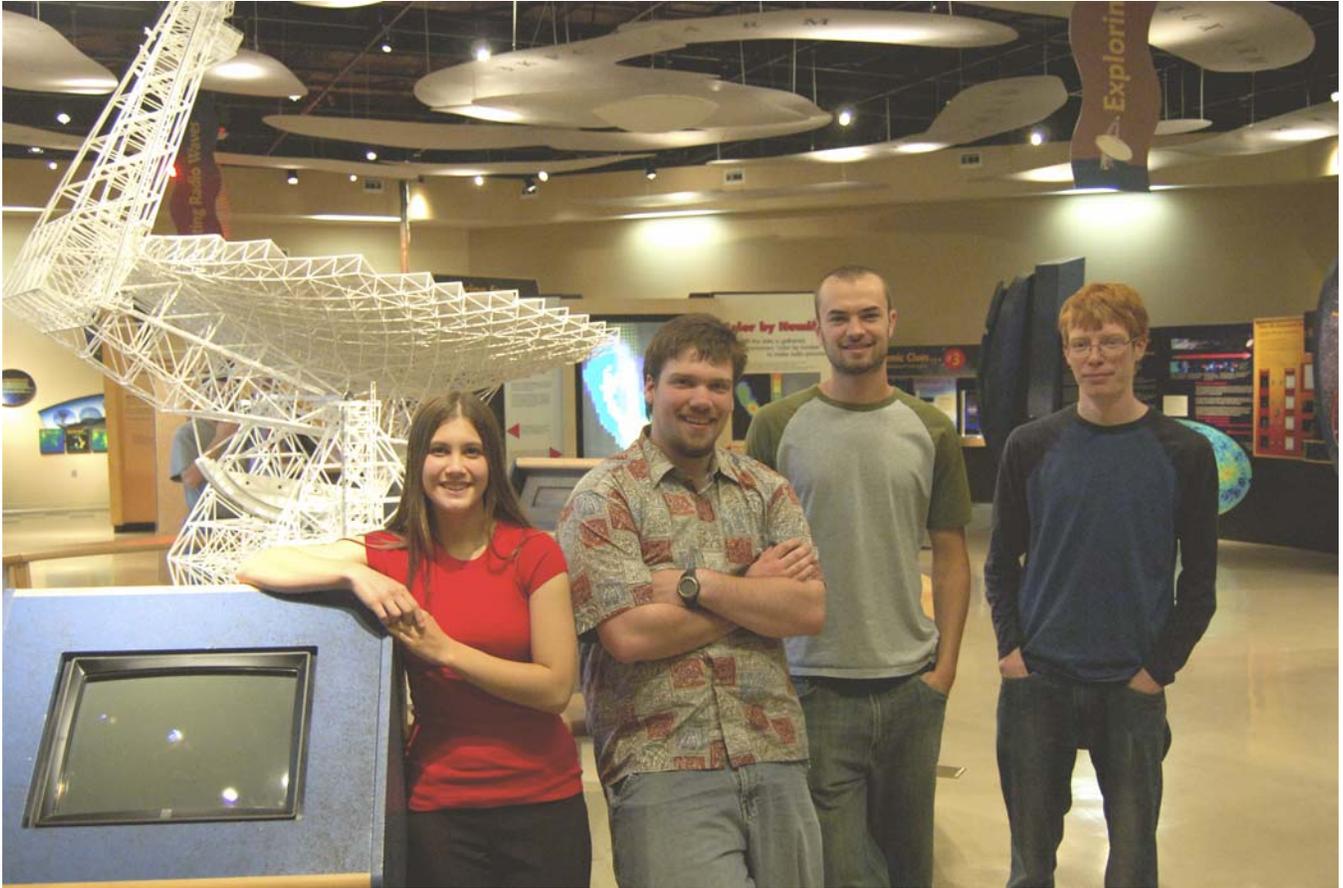
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## Charlottesville Summer 2008 Schedule

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- 06 May 08 - **Start Date** : Claudia Cyganowski
- 19 May 08 - **Start Date** : Jessica Coakley, Anthony Hamzeh, Daniel Lacasse, Bryan Murphy
- 26 May 08 - **NRAO Holiday (Memorial Day)**
- 27 May 08 - **Start Date** : Delia Mocanu, Brian Sacash, Charli Sakari, Evan Schneider, Tim Pennucci
- 02 Jun 08 - **Start Date** :
- 09 Jun 08 - **Start Date** : Matt Schenker
- 11 Jun 08 - 01:00-03:00pm, **GBT Observing Projects Discussion** (CV230)
- 13 Jun 08 - 02:30-03:30pm, **Welcome Reception** : Students and Staff (ER Foyer)
- 16 Jun 08 - **Start Date** : Allison Hammond
- 18 Jun 08 - 01:00-03:00pm, **GBT Observing Projects Discussion** (CV230)
- 15 Jun 08 - **Father's Day**
- 23 Jun 08 - 02:00-03:30pm, **SS Lecture** : *Jim Condon, Essential Radio Astronomy* (CV230)
- 25 Jun 08 - 29 Jun 08 - **CV Summer Student Trip to GB**
- 28 Jun 08 - 12:00-05:00pm, **NRAO Picnic (Chris Greene Lake)**
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- 01 Jul 08 - 10:00-10:30am, **Library Tour** : *M. Bishop*, (Library)
- 02 Jul 08 - 01:00-02:00pm, **SS Lecture** : *Ken Kellermann, An Overview of the History of Radio Astronomy* (CV230)
- 02 Jul 08 - 02:00-03:00pm, **SS Lecture** : *Ellen Bouton, The NRAO Historical Radio Astronomy Archive* (CV230)
- 09 Jul 08 - 01:00-03:00pm, **SS Lecture** : *Tony Remijan , Astrochemistry* (CV230)
- 14 Jul 08 - 02:00-03:00pm, **SS Lecture** : **Al Wootten, Molecules, Molecular Emission, and ALMA (CV230)**
- 15 Jul 08 - 03:00-04:30pm, **NRAO Technology Center Tour**
- 16 Jul 08 - 01:00-3:00pm, **SS Lecture** : *Jeff Mangum , Starburst Galaxies* (CV230)
- 23 Jul 08 - 02:00-03:00pm, **SS Lecture** : *John Hibbard , Interaction Driven Galaxy Evolution: The Fate of Gas* (CV230)
- 28 Jul 08 - 01:00-03:00pm, **SS Lecture** : *Juan Uson , The Universe in 2008* (CV230)
- 06 Aug 08 - 01:00-03:00pm, **SS Lecture** : *Dana Balsler , Primordial and Stellar Nucleosynthesis* (CV230)
- 05 Aug 08 - 12:00-1:00pm, **REU Project Presentations by Jessica Coakley, Anthony Hamzeh, Daniel Lacasse, Bryan Murphy** (CV230)
- 08 Aug 08 - 12:00-1:00pm, **REU Project Presentations by Evan Schneider, Tim Pennucci, Charli Sakari** (CV230)
- 08 Aug 08 - **Last Day** : Bryan Murphy, Daniel Lacasse, Jessica Coakley, Evan Schneider, Anthony Hamzeh

- 12 Aug 08 - **Last Day** : Tim Pennucci
- 13 Aug 08 - 12:00-1:00pm, **REU Project Presentations by Matt Schenker, Brian Sacash, Claudia Cyganowski, Delia Mocanu (CV230)**
- 13 Aug 08 - **Last Day** : Allison Hammond, Delia Mocanu
- 15 Aug 08 - **Last Day** : Charli Sakari, Brian Sacash
- 17 Aug 08 - **Last Day** : Claudia Cyganowski
- 22 Aug 08 - **Last Day** : Matt Schenker



**Shown in the NRAO Visitor Center are the Green Bank Summer Students. L-R are Stephanie Moats, Anthony Woody, Marc Eimers, and Colin Slater.**

### **3. Site Specific Activities: Green Bank, WV**

The 2008 REU/RET program at NRAO Green Bank was under the direction of Toney Minter and Sue Anne Heatherly. There were five students and two teachers in the 2008 Summer Research Program at NRAO-GB. Four students were supported by the NSF Research Experience for Undergraduates (NSF REU) and one of the students was supported by the NRAO Graduate Summer Student Program (NRAO GRP). The two teachers were supported by the Research Experience for Teachers Program (RET). The photograph above shows several of the summer students standing in front of the Green Bank Telescope model in the Green Bank Science Center. From left to right are Stephani Moats (NSF REU), Anthony Woody (NSF REU), Marc Eimers (NSF REU), and Colin Slater (NSF REU). The Green Bank summer student/teacher calendar is given below. There was a special set of lectures given to the students by scientists and engineers on Green Bank staff. In addition, the summer students were able to participant to varying degrees in several workshops that were held in Green Bank. These include a Chautauqua Short Course on Astronomy, the Society of Amateur Radio Astronomers (SARA) meeting, the Mid Atlantic Astronomical Society Star Party and the Pulsar Research Collaboratory Teacher Workshop. There was also a weekly Science Lunch with the students every Thursday and regular soccer and volleyball games.

In late June the Green Bank summer students hosted a site visit by the NRAO Charlottesville summer students. They were responsible for showing the Charlottesville students all of the facilities at Green Bank as well as

taking the students on a tour of the GBT. During the summer, the Green Bank students, in conjunction with the NRAO Charlottesville students, conducted their own observational projects on the GBT, performing OH observations of several comets, a study of Radio Recombination Lines towards HII regions, a survey searching for extra-galactic HI and a study of Formyldehyde in Infrared Dark Clouds. The NRAO Green Bank students were invited to present a lecture on their summer research to the the West Virginia Govener's School for Math and Sciences. At the end of the summer, the students gave the staff a seminar where they presented the results of their summer research projects.

They also produced a short report describing this work. REU students and RET participants plan to attend the AAS meeting in Long Beach, California in January 2009 to present posters on their summer research projects.

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## Green Bank Summer 2008 Schedule

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- E Thu - 12:00 - **Science Lunch (Residence Hall Lounge)**
- E Sun - 18:00 - **Volleyball (Hannah House)**
- E Thu - 18:30 - **Soccer (Fields behind Elementary School)**
  
- 22 May 08 - **Colloquium by Peter Illot (1:30 in Auditorium)**
- 30 May 08 - **Science Talk by Jens Kauffman (11:00 in Residence Hall Lounge)**
- 03 Jun 08 - **Colloquium by Larry Morgan (3:30 in Auditorium)**
- 05 Jun 08 - **Colloquium by Jeremy Bailin (4:00 in Auditorium)**
- 10 Jun 08 - **Colloquium by Robert Minchin (3:30 in Auditorium)**
- 17 Jun 08 - **Colloquium by Dave Smith (3:30 in Auditorium)**
- 23 Jun 08 - **Colloquium by Gerrit Verschuur (11:00 in Auditorium)**
- 24 Jun 08 - **Colloquium by Danielle Kettle (3:30 in Auditorium)**
- 22 Jul 08 - **Colloquium by Amy Lovell (3:30 in Auditorium)**
- 28 Jul 08 - **Colloquium by Yuri Kovalev (3:30 in Auditorium)**
- 01 Aug 08 - **Colloquium by Ron Maddalena (1:30 in Auditorium)**
- 12 Aug 08 - **Colloquium by Kelly Holley-Bockelmann (3:30 in Auditorium)**
  
- 28 May 08 - **Summer Student GB Site Safety Talk (9:00 Summer Student Office)**
- 27 May 08 - **Summer Student Lecture - How to use the 40 foot - Sue Ann Heatherly (1:00 Science Center)**
- 02 Jun 08 - **Summer Student Orientation Meeting (1:30 Bsmt. Conf. Room)**
- 03 Jun 08 - **GBT Tour (morning - TBD)**
- 03 Jun 08 - **Summer Student Lecture - Radio Astronomy - Jay Lockman (1:30 Bsmt. Conf. Room)**
- 06 Jun 08 - **Summer Student Lecture - History of Radio - Gary Anderson (1:30 Bsmt. Conf. Room)**
- 10 Jun 08 - **Summer Student Lecture - Star Formation - Larry Morgan (1:30 Bsmt. Conf. Room)**
- 13 Jun 08 - **Summer Student Lecture - CICADA Project - John Ford (1:30 Bsmt. Conf. Room)**
- 17 Jun 08 - **Summer Student Lecture - Comets - Amy Lovell (1:30 Bsmt. Conf. Room)**
- 24 Jun 08 - **Summer Student Lecture - Basics of Observing with the GBT - Toney Minter (1:30 Bsmt. Conf. Room)**
- 01 Jul 08 - **Summer Student Lecture - Astrobiology - Glen Langston (1:30 Bsmt. Conf. Room)**
- 08 Jul 08 - **Summer Student Lecture - Front Ends - Steve White (1:30 Bsmt. Conf. Room)**
- 15 Jul 08 - **Summer Student Lecture - VLBI - Frank Ghigo (1:30 Bsmt. Conf. Room)**
- 18 Jul 08 - **Summer Student Lecture - Focal Plane Arrays - Roger Norrod (1:30 Bsmt. Conf. Room)**

- 22 Jul 08 - Summer Student Lecture - Pulsars - Dunc Lorimar or Maura McLaughlin (1:30 Bsmt. Conf. Room)
- 29 Jul 08 - Summer Student Lecture - PTCS - Todd Hunter (11:00 GB-137)
- 04 Jun 08 - 06 Jun 08 - Chautauqua (Auditorium)
- 25 Jun 08 - 27 Jun 08 - COMETS teachers
- 28 Jun 08 - 30 Jun 08 - Society of Amateur Radio Astronomers (Science Center)
- 02 Jul 08 - 05 Jul 08 - Green Bank Star Quest the Fifth (Science Center)
- 06 Jul 08 - 17 Jul 08 - Pulsar Research Collaboratory Teacher Workshop (Science Center)
- 21 Jul 08 - 25 Jul 08 - Pulsar Research Collaboratory Teacher Workshop (Science Center)
- 03 Aug 08 - 15 Aug 08 - Governor's School for Math and Science (Science Center)
- 10 May 08 - Star Party (dusk at Science Center)
- 06 Jun 08 - Friday night Movie Fest (19:00 in the Science Center)
- 07 Jun 08 - Star Party (dusk at Science Center)
- 01 Aug 08 - Friday night Movie Fest (19:00 in the Science Center)
- 01 Aug 08 - Star Party (dusk at Science Center)
- 04 Aug 08 - Garth Newell Concert (19:30 in the Science Center)
- 25 Jun 08 - 29 Jun 08 - CV students visit
- 25 Jun 08 - GBT Observations - Extra-galactic HI project - 17:30-21:00
- 25 Jun 08 - GBT Observations - Radio Recombination Lines project - 21:00-23:30
- 25 Jun 08 - GBT Observations - Formaldehyde project - 23:30-04:30
- 26 Jun 08 - GBT Observations - Radio Recombination Lines project - 04:30-07:00
- 26 Jun 08 - GBT Observations - Extra-galactic HI project - 17:30-21:00
- 27 Jun 08 - GBT Observations - Cometary OH project - 08:30-12:30
- 05 Aug 08 - Summer Student Presentations to WV Governor's School (19:00 in Science Center Auditorium)
- 06 Aug 08 - Summer Student Presentations to NRAO Staff (1:00 in Auditorium)
- 19 May 08 - Anthony Woody Starts
- 19 May 08 - Stephanie Moats Starts
- 19 May 08 - Colin Slater Starts
- 07 May 08 - Marc Eimers Starts
- 08 Aug 08 - Colin Slater's Last Day
- 11 Aug 08 - Marc Eimer's Last Day
- 11 Aug 08 - Stephanie Moat's Last Day
- 11 Aug 08 - Anthony Woody's Last Day



At the VLA site are the Socorro Summer Students. BR, L-R, are Fred Davies, Josh Marvil, Ben Breslauer, Crystal Anderson, Alex Savello, & Bobby Edmonds. FR, L-R, are Sarah Streb, Kiruthika Devaraj, & Stephanie Capen.

## 4. Site Specific Activities: Socorro, NM

The 2008 REU program at NRAO Socorro was under the direction of Amy Mioduszewski. There were eight students and two teachers in the 2008 Summer Research Program at NRAO Socorro. Four of the students participated via the NSF Research Experience for Undergraduates (NSF REU) program, three were supported by the NRAO Graduate Research Program (NRAO GRP), and one was supported by the NRAO Undergraduate Research Program (NRAO uGRP). The two teachers participated via the NSF Research Experience for Undergraduates (NSF RET). The above photograph shows all of the students and one of the teachers at the VLA. From the left in back row are Fred Davies (NSF REU), Josh Marvil (NRAO GRP), Ben Breslauer (NSF REU), Crystal Anderson (NRAO GRP), Alex Savello (NSF REU) and Bobby Edmonds (NRAO GRP), in the front row are Sarah Streb (NSF RET), Kiruthika Devaraj (NRAO GRP) and Stephanie Capen (NSF REU). Not shown is Santosh Madhavan (NSF RET). The Socorro summer students had a variety of activities to take part in, as listed in the calendar below. In addition to the scheduled events, there were weekly activities for the students and teachers, including "Wednesday Lunch" (free pizza for students!) with scientific talks and Tuesday Science Tea held in the upstairs lounge. The group toured two observatories: the VLA and Apache Point

Observatory. They also toured the Energetic Materials Research and Testing Center located in Socorro. The students and teachers also attended the Eleventh Synthesis Imaging Workshop, a week long school organized by NRAO and held at the New Mexico Institute of Mining and Technology and NRAO in Socorro.

The students and teachers also gave public tours of the VLA, which is an important outreach activity since it is the only period of the year that there are public tours at the VLA every weekend.

The scientific highlight of the summer was the two student-led observational projects, one using the VLA and the other using the VLBA. One group used the VLA to search for radio emission from exoplanets. If radio emission from exoplanets could be detected, this would open a new area of physical exploration for these objects. The VLBA project targeted the young star system V773 Tau. This is a quadruple system and two of the stars show variable non-thermal emission. The flux density of these two stars is shown to increase when the stars are closest together, implying an interaction of the magnetospheres of the stars, however the stars have never been observed at a resolution that show if there are structural changes to accompany the rise in flux density. The students decided to observe this system at a high resolution (a few stellar radii) in order to resolved the structure of these stars. At the end of the summer, the students gave a series of 15 minute talks on their projects, and produced a short report describing their summer research (sent under separate cover).

## Socorro Summer 2008 Schedule

### Weekly Events

Day	Date	Time	Item	Location
Tue		4 pm	Science Tea (free cookies!)	3rd Floor Lounge
Wed		12 n	Pizza Lunch (free pizza!)	Auditorium
Sat	Jun 21 - Aug 3	10 am - 4 pm	Tours	VLA Site

### Daily Calendar

Day	Date	Time	Item	Location
Tue	Jun 3	9 am	Safety Meeting	Auditorium
Tue	Jun 3	5:30 pm	Dinner with Summer Student Coordinator	Leave the AOC
Tue	Jun 10	9 am	Synthesis Imaging Workshop begins	Workman 101
Tue	Jun 17	12:30 pm	Synthesis Imaging Workshop ends	Workman 101
Fri	Jun 20	8:00 am	How to give a VLA tour - Judy Stanley	Leave from AOC
Wed	Jun 25	2:00 pm	VLA/VLBA Observing Project Meeting	SOC-317
Mon	Jun 30	3:00 pm	VLA/VLBA Observing Project TAC	SOC-317
Tue	Jul 1	10:00 am	Explosive Binaries in the Milky Way - M. Rupen	SOC-317

Fri	Jul 4		NRAO Holiday (Independence Day)	
Tue	Jul 8	10:00 am	High Redshift Universe - J. Wagg	SOC-317
Wed	Jul 9	2:30 pm	Star Formation - D. Shepherd	Auditorium
Tue	Jul 15	10:00 am	From Black Holes to Radio Galaxies - J. Eilek	SOC-317
Thu	Jul 17	2:00 pm	Astronomical Masers - Mark Claussen	SOC-317
Tue	Jul 22	10:00 am	Solar System - B. Butler	Auditorium
Wed	Jul 23	12:00 n	RET Presentation - S. Streb	Auditorium
Wed	Jul 23	2:00 pm	Ruby Payne-Scott: The First Woman Radio Astronomer - M. Goss	SOC-317
Thu	Jul 24	8:15 am	Trip to Apache Point Observatory	Leave from AOC
Mon	Jul 28	9:00 am	Tour of EMRTC - Meet Judy Stanley in AOC Lobby at 8:50	EMRTC
Wed	Jul 30	12:00 n	RET Presentation - S. Madhavan	Auditorium
Thu	Jul 31	10:00 am	Local Galaxies - D. Meier	SOC-317
Fri	Aug 1	5:30 pm	No-host dinner with McDonald REUs	Socorro Springs
Wed	Aug 6	12:00 n	Summer Student Presentations - R. Torres, A. Savello	Auditorium
Fri	Aug 8	11:00 am	Summer Student Presentations - B. Breslauer, B. Edmunds	Auditorium
Fri	Aug 8	12:00 n	End-of-summer lunch	Socorro Springs
Wed	Aug 11	12:00 n	Summer Student Presentations - C. Anderson, J. Marvil	SOC-317
Wed	Aug 14	1:00 pm	Summer Student Presentations - S, Capen, K. Devaraj	Auditorium
Wed	Aug 20	12:00 n	Summer Student Presentation - F. Davies	Auditorium
Mon	Aug 30		End of Summer Write-Ups	email to Amy M.

## 5. REU Project Summaries

The symbol to the right indicates students who were supported under the [National Science Foundation \(NSF\) Research Experiences for Undergraduates \(REU\)](#) program. All other students were supported under the [NRAO Summer Student Research Assistant Program](#). Follow this link for a list of [all student programs at the NRAO](#). You can also find student projects titles from 1991 to present [in tabular form](#).



### 2008 Summer Students

**Crystal Anderson, of Western Washington University,  
worked with Debra Shepherd on**

#### **X-ray emission from embedded young massive stars**

We would like Crystal to look at correlations between X-ray emission and the location of embedded young massive stars as traced by UC HII regions from archival VLA data. The goal is to research any correlation between the X-ray and radio emission to discriminate between the possible physical processes responsible for the X-ray emission. Possible candidates are shocks from flows/jets or accretion, magnetic reconnection events between disk-star, colliding binary winds, and inverse Compton scattering.

**Benjamin Breslauer, of Oberlin College,  
worked with Dale Frail on**



#### **Astronomy in the Time Domain**

The radio sky is not static and unchanging, but rather there exists a rich variety of objects that vary on a range of timescales. Many possible objects may be responsible for these variations, including, but not limited to, brown dwarfs, old neutron stars, and high redshift galaxies. This summer, we looked into a number of these objects. We searched for radio emission from all known AM CVn stars, and analyzed data from a new type of radio supernova search, finding a number of possible optically-obscured SNe. In addition, we took nightly observations of the many sky positions with the VLA in order to look for radio transients that exist on day-long timescales. We reduced the data in near-real-time in order to make follow-up observations with telescopes in other areas of the EM spectrum, including Palomar and SWIFT.

**Stephanie Capen, of Eastern Nazarene College,  
worked with Lorant Sjouwerman & Mark Claussen on**



## **Infrared colors of evolved stars as a tracer of maser emission**

Stephanie's REU project investigated a universal translation between the near- and mid-infrared color schemes used in the different space missions (IRAS, MSX, Spitzer). The project included the retrieval of the data from the individual web servers, development of computer programs to match data from the different missions to single sources, and predict the detection of SiO masers from the colors of the different space missions. She was able to find two MSX color-color diagrams (A-D vs. A-E & A-E vs. C-E) that clearly translated the IRAS two-color diagram regions (as done by van der Veen and Habing 1988) into a similar sequence of distinguishable MSX color-color regions. She also looked at a list of 86 GHz SiO maser detections and statistically predicted the probability of finding SiO maser emission from the MSX colors she had selected for her figures. In first instance the scheme is being applied and working for evolved stars with circumstellar envelopes, after which it can be tuned to include, e.g., OH and H<sub>2</sub>O masers, proto-planetary nebulae, planetary nebulae, or even high-z starburst galaxies.

**Jessica Coakley, of Bridgewater College,  
worked with Jeff Mangum on**



## **The Star Formation Environment of Sharpless 106**

Sharpless 106 (S106) is a bipolar HII region in the Cygnus X molecular cloud complex. It has been studied at radio, infrared, and optical wavelengths, but some aspects of the region still remain a mystery. The purpose of my project was to (1) Create a kinetic temperature map of the NH<sub>3</sub> from the (1,1) and (2,2) line data; (2) develop a model for S106 to explain the dynamics of the region, including the IRS sources, the dense gas structure, S106IR, S106FIR, the bipolar outflows, and the temperature; (3) determine an evolutionary scenario for S106 based on the existing knowledge of the region. The central exciting star of S106 is S106IR/IRS4, which is buried in the dense molecular cloud core from which it recently formed. S106IR has created bipolar outflows bifurcated by a dark lane in the optical and infrared. The dark lane has been explained as a disk (Sibille et al. 1975), torus (Little et al. 1995), ring (Luoshin et al. 1990), or a clumpy molecular cloud (Barsony 1989). A clumpy molecular cloud seems most likely since this is a young stellar object in the stages before disk formation. The outflows have created an ionization front bounded by several IRS sources that were identified by Gehrz et al. in 1981. These IRS sources include S106FIR/IRS3, a possible Class 0 protostar, or more likely just a heated clump that may eventually form a protostar. A C-shock is created in front of the ionization front, which heats up the surrounding molecular cloud, giving it a temperature of between 25 and 40 K with even warmer clumps. The distance to the region is highly uncertain because it is in a tangent arm of our galaxy. Most authors adopt a distance of 600 pc from Staude et al. in 1982, however Schneider et al suggested a distance of 1.7 kpc in 2007 to identify S106 with the Cygnus X region, which seems likely. S106 is probably representative of a system in which a late Class 0 or early Class I protostar is forming in a large, extended molecular cloud, which explains the dynamics of the region.

**Claudia Cyganowski, of University of Wisconsin-Madison,  
worked with Crystal Brogan on**

## **Probing the Nature of Extended Green Objects: A New Sample of Massive Protostellar Candidates**

This project explores the nature of a new sample of massive protostellar candidates identified on the basis of extended 4.5 micron emission in the Spitzer GLIMPSE survey of the Galactic plane. These sources, referred to as "EGOs" (Extended Green Objects) are thought to harbor massive protostars in early stages of evolution, that have been missed by earlier surveys like IRAS. The extended 4.5 micron emission is thought to trace shocked gas in massive protostellar outflows; the goal of my project was to test this hypothesis via EVLA surveys for 6.7 GHz and 44 GHz methanol masers towards a sample of ~ 30 EGOs. The detection rate for 6.7 GHz methanol masers--found only in massive star forming regions-- towards EGOs is at least 64%, significantly higher than the detection rate in previous IRAS and water-maser selected surveys. The subsample of EGOs with 6.7 GHz detections was searched for 44 GHz Class I methanol masers, which are indicative of molecular outflows: the detection rate was 89%. These results indicate that extended 4.5 micron emission is identifying a population of very young massive protostellar objects, with active outflows, most likely powered by ongoing accretion. The next stage of this project is to reduce recently-acquired high resolution mm observations of a subsample of 4 EGOs to identify and characterize the driving protostars and study the outflow chemistry.

**Frederick Davies, of New Mexico Tech,  
worked with Craig Walker and Joan Wrobel on**



## **Relative Motions of two Massive Galaxies in the Virgo Cluster**

We used existing VLBA phase reference data at 43 GHz to look for changes in the relative positions the cores of M87 and M84. M87 is the dominant galaxy of the Virgo Cluster and M84 is one of the most massive cluster members. The object of our project is to obtain a time sequence of relative position measurements with accuracy significantly under 100 microarcseconds using existing data from 2001, 2004 and from an M87 movie project made during 2007 and early 2008. A measurement of, or upper limit for, a linear motion would constrain the relative motion of the two galaxies and has the possibility to provide the first transverse motion measurement of a galaxy in the heart of the Virgo Cluster. The dense data from the recent movie project will also be used to constrain any changes of the position of the brightest feature. If that feature is actually a feature of the jet that is offset from the black hole, it could potentially wander around depending on jet strength or other factors. For the summer project, the student reduced the phase referencing data from many of the recent data sets. In the process, the student did the basic calibration and imaging for many of the data sets and repeated that calibration for all data sets involved in the proper motion project to insure that consistent methods were used. During the reduction, the student determined improved atmospheric calibration using multi-band delay measurements of many calibrators, where available, or phase rate measurements on M87 and two other calibrators. An attempt was also made to improve the calibration for the earlier data since any rate measurement depends very strongly on the 2001 data. As a byproduct of the imaging effort, a light curve and images were produced that will be used to constrain the location of the source of a TeV flare that occurred during the early 2008 observations.

**Kiruthika Devaraj, of Georgia Institute of Technology,  
worked with Brigitte Hesman & Bryan Butler on**

## **Radio Observations and Radiative Transfer Modeling of Planetary Atmospheres**

There is significant uncertainty in the structure of the deep atmosphere of Uranus. Uranus has just passed its equinox in 2007 and this is a crucial time for re-investigation of previous data and comparison against recent observations to look for changes, with season, in the deep atmosphere. Radio observations are well suited to sensing the middle to lower troposphere and are used to determine the temperature and chemical structure of Uranus. This project would involve data reduction of current and previous VLA observations of Uranus. In addition, radiative transfer models of Uranus' atmosphere will also be updated in order to improve temperature and abundance determinations from VLA observations. Modifications to the model could also be used to investigate emission from the atmosphere of Venus. This project is best suited to a graduate student interested in planetary research at radio wavelengths. Three main topics were completed during Ms. Devaraj's project: i) the brightness temperature model for Uranus was updated to work in the microwave region; ii) VLA Uranus data from 2006 and 2007 were reduced; and iii) Venus data from 1996 and 1997 were reduced. Specifically the following in each topic was covered: i) K. Devaraj has worked extensively on updating the absorption due to the microwave absorbers NH<sub>3</sub>, H<sub>2</sub>S, H<sub>2</sub>O, PH<sub>3</sub>, and CO for the Uranus model. In addition, the latest saturation vapor pressure curves and deep atmosphere abundances have been updated for these species. While working on these topics it was determined that cloud opacity was an important component missing from the model and this module is now almost complete. Therefore, the update to the Uranus model has been extensive which will allow more accurate temperature and abundance retrievals to be performed from VLA observations. ii) Three data sets were reduced during K. Devaraj's summer project. A C-band observation from May 2006, and two K-band observations from fall 2007. These observations show Uranus with two bright poles; an unexpected feature since its north pole has been in darkness for nearly 40 years. The data reductions resulted in maps which will then be used along with the updated model to determine tropospheric temperatures of the warm polar regions. iii) Three data sets were reduced during K. Devaraj's summer project; Venus X-Band data taken in April, 1996 and U-Band and K-Band data taken in December, 1997. The small tilt of Venus (2.6 degrees) results in both poles almost always visible to the sun, and therefore both hemispheres are expected to be at the same temperature. The U and K band maps show that the southern hemisphere is clearly brighter than the northern hemisphere. We are still trying to understand the reason behind this difference in brightness temperature in the two hemispheres.

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**Robert Edmonds, of The University of New Mexico,  
worked with Jeff Wagg & Chris Carilli on**

## **An EVLA study of H<sub>2</sub>O megamasers in submm galaxies**

Traditional methods of measuring redshifts for submm galaxies requires large amounts of telescope time in order to 1) localize the correct optical/infrared counterpart with VLA interferometry at 1.4 GHz, and then 2) measure a redshift through deep spectroscopy with 10-m class optical telescopes. There are many uncertainties in this process, and the success rate for bright submm galaxies is ~40%. Alternative methods, such as broadband searches for CO line emission, may be more effective and cheaper with the current generation of mm-to-cm wavelength facilities. This proposed study explores a new technique involving searches for low frequency water megamaser line emission in SMGs. With the newly available EVLA C-band receivers, it is now possible to search for this emission line in submm galaxies with secure redshifts and previously detected CO line emission.

We observe the strongly lensed submm galaxy, SMM J16359+6612 at  $z=2.5$  and the student will lead the data reduction and write-up of this experiment. The paper has been submitted to the *Astronomical Journal* for publication.

**Marc Eimers, of University of Colorado at Boulder,  
worked with Maura McLaughlin and Dunc Lorimer on**



### **140 Foot pulsar observation commissioning**

MIT/Lincoln labs in MA is currently using the 140' telescope in Green Bank, WV to study the Earth's ionosphere. They are not operating the telescope around the clock however, so astronomers at WVU are working with the NRAO to develop a new data acquisition system to observe pulsars with when the telescope is not being used. My project has been to help with developing and testing this new system. We are using the Parkes Spectrometer, designed by Peter McMahan, as the new pulsar backend for the telescope. One of the first things I did with my advisors, Duncan Lorimer and Maura McLaughlin, was to make a data-taking control graphical user interface to simplify the observation process. We then proceeded to make pulsar timing observations of eight different known pulsars. We began to notice strange behavior in the off-pulse noise levels of the integrated pulse profiles of the different pulsars. We wanted to try and begin to localize the cause of the problems by hooking up an artificial pulsar to the spectrometer. The artificial pulsar machine hadn't been used in years and it was hard to find anyone who still remembered how to use it, so we documented our testing procedure so that others may refer to it in the future when the machine needs to be used again. Our testing seems to show that the cause of the unexpected behavior in the off pulse noise is not located within the spectrometer itself. However, when the artificial pulse period was set to be very small (on the order or milliseconds) a sort of "bleed-off" feature was seen at the tail end of the pulse. It has yet to be determined whether this is coming from the spectrometer or the artificial pulsar machine itself. The results of the timing observations show that the spectrometer is indeed putting in the correct time stamps. In addition to the timing observations, scintillation observations of the known pulsar B0329+54 were carried out. The diffractive parameters that were calculated from these observations were very questionable, but the length and the center frequency of the observations were less than ideal.

**Allison Hammond, of Western Albemarle High School,  
worked with Jeff Mangum on**

### **Parent and Daughter Species Evolution in Comet Hale-Bopp**

Measurements of the CO, HCN, H<sub>2</sub>CO, and HCO<sup>+</sup> emission distribution from comet Hale-Bopp during perihelion passage in March and April 1997 measured a wide range of emission intensities and distributions. Within these measurements lie clues to the formation and evolution of molecular species in comets, which can lead to information on the constituents of the pre-solar nebula. The analysis of these measurements will result in a better understand of parent and daughter species formation and evolution in comets.

**Anthony Hamzeh, of James Madison University,  
worked with Tony Remijan on**



## **Probing the Physical and Chemical Properties of Astronomical Environments using Spectral Line Survey**

Spectral line surveys provide powerful tools to analyze the coupled dynamical and chemical evolution of molecular clouds. In a survey, many lines of a single species are observed at similar sensitivities, diminishing the errors associated with derived quantities. For example, a particular problem arises in deriving accurate abundances because of overlapping identifications of molecular species. Surveys provide the best means of avoiding this problem by revealing intensity changes in lines of a given species. The student willing to work on this project will investigate the complete 2mm spectral line survey (130-170 GHz) taken with the NRAO 12m telescope between 1993 and 1995 toward the following sources: Sgr B2N, Sgr B2OH, IRC +10 216, Orion (KL), Orion-S, W51M and W3(IRS5). The student will pick one or several of the above sources to further investigate the physical and chemical environments of these very interesting regions and to compare the 12m observations with other published spectral line surveys toward these sources. In addition, the student will have the opportunity to work on a new survey of the Sgr B2N region using the GBT. Overall, the primary goal of the project is to provide the observational constraints for both the physical environment and the complex chemistry, allowing us to investigate the correlations between the physical and chemical evolution of astronomical environments.

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**Daniel Lacasse, of James Madison University,  
worked with Pat Murphy on**



## **Web Image Gallery Refactoring**

This project involved participation in updating, modernizing, and improving of NRAO's [Image Gallery](#). The current image gallery contains approximately 360 images, with images added weekly, and the subject matter covers such diverse areas as Astronomy, History, Telescopes, and Instrumentation.

The migration of the gallery to its own virtual host <http://images.nrao.edu/> presented a unique opportunity for study and research into optimal ways to organize and present both the metadata and the actual images themselves. Technologies currently in use include the scripting languages [PHP](#) and Perl, and the MySQL database server, on an Apache/Linux platform.

The main index page was reconstructed to display all thumbnail images at the same size (100x75 pixels) in a regular grid, for a cleaner appearance. A technique was developed using the ImageMagick toolset to re-generate all thumbnails to this size, including optimal cropping. The *Advanced Search* option was repaired and enhanced to more accurately query SIMBAD as needed, to support more user friendly options and to permit searches with multiple search parameters.

The image submission and approval process was automated and streamlined. The downloading, naming, resizing and storing of Image Gallery submissions can now be almost completely automated.

Progress was made on an implementation of image tagging at submission approval time, using the [Astronomy Visualization Metadata](#) (AVM) Standard which has been [documented by IVOA](#). Tagging NRAO images in the AVM standard will allow them to be cataloged and offered through advanced search portals.

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**Joshua Marvil, of NMT,  
worked with Frazer Owen on**

### **Understanding the nature of the microJy radio source population**

Josh Marvil, New Mexico Tech continued to work with Jean Eilek and Frazer Owen this summer on a project to understand the nature of the microJy radio source population and the radio-FIR relation. These sources were thought by many to be mostly star-forming galaxies with median luminosities near (or greater than that of Arp220. However, their median size is quite large,  $> 1''$ , given their high median redshift  $\sim 1$ . This size corresponds to  $\sim 10$  kpc, unlike similar local sources whose radio size is  $< 100$ pc. We refined our study of the spatial coincidence of the radio and optical emission for the SWIRE deep field and showed that the degree of coincidence depends on radio luminosity. We also studied stacks of the 90cm radio survey in order to estimate the mean spectral indices in subsets selected by radio luminosity and redshift. These same subsets had been studied for FIR luminosity by stacking deep Spitzer MIPS data and classifying each subset as AGN or star-formation driven based on the radio-FIR relation. We found an interesting trend with redshift and AGN vs star-formation for spectral flattening. We spent most of the summer trying to understand this trend. This led to studying various mechanisms for flattening the radio spectrum at low frequencies and how such processes are related to understanding the origin of the radio-FIR correlation.

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**Stephanie Moats, of New Mexico Tech,  
worked with Glen Langston on**



### **GBT searches for new classes of interstellar molecules**

Searches for new classes of interstellar molecules will be performed by "folding" of GBT spectra. The broad bandwidth radio spectra will be aligned in velocity and weighted by expected line brightness to achieve optimum sensitivity to new groups of molecules. The student will help with IDL programming to average spectra; shifting and scaling the data based on chemical models for the expected spectra. This work is important for studying complex molecule chemistry in the interstellar medium.

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**Delia Mocanu, of New Mexico Tech,  
worked with Bob Garwood on**

### **Design Tool for Display of and Interaction with Large Spectral-Line GBT Data Sets**

Instrumentation efforts at the Robert C. Byrd Green Bank Telescope (GBT) are increasingly focused on multi-pixel receivers as well as wide-bandwidth backends for data acquisition, producing large quantities of spectral-line data during an observation. Current GBT data analysis tools lack the ability to display and interact with

these large data sets as a whole. For example, viewing large chunks of data simultaneously can be useful in identifying problems in the data (e.g. RFI) as well as discerning structure within the dataset. In this project, the student started by conducting a brief survey of the existing solutions to similar problems at other radio telescopes (e.g. aips++/CASA, JCMT, Arecibo). The student created a prototype tool that does the basic display, zoom and pan, and flag and unflag operations on a GBT dataset.

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**Bryan Murphy, of Virginia Polytechnic Institute and State University,  
worked with Nicole Radziwill on**



## **Applying Semantic Web Technologies and Ontologies to the NRAO Data Vault**

The NRAO Data Vault is a web-accessible collection of NRAO science data from the GBT, VLA and VLBA, which aims to provide convenient access to browse and download data products which have related keywords which match a free-text (Google-like) search query. Right now, an astronomer can search for entries in the Data Vault based on keywords such as project name, name of the astronomical source, and instrumentation used to make the observation. This project involves extending the capabilities of the search function by creating a scheme for records in the Data Vault to be searched based on "common" categories of astronomical objects, such as molecular clouds, edge-on and face-on galaxies, and binary pulsars. Determining which categories are important by reviewing surveys and the scientific literature, and researching available tools that might be useful in putting together this project (e.g. Virtual Observatory services) will be required.

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**Timothy Pennucci, of Columbia University, Columbia College,  
worked with Scott Ransom on**

## **Dynamic Power Spectra: Searching for Compact Binary Pulsars**

Some of the most scientifically useful pulsars are those in compact binary orbits (orbital periods  $P_{orb} < 4-5$  hours). Unfortunately, strong Doppler accelerations make finding these pulsars very difficult. One of the more promising techniques to find these objects utilizes Dynamic Power Spectra (DPS), which is sensitive to binary pulsars when the observation length is comparable to the orbital period. We have improved the method by which we create DPS by including a constant frequency derivative acceleration search with interbinning in each DPS segment. We have developed a beta version of a DPS search algorithm that is tuned to find pulsars where the orbital period is approximately equal to the observation duration. We have many terabytes of globular cluster data from the GBT which likely contain unknown compact pulsar binaries. A thorough search of this data is ongoing and if new pulsars are found we will then determine "instant" timing solutions using the archival data.

**Brian Sacash, of Ohio Northern University,  
worked with Ron DuPlain on**



## **Data Preservation and Access for the NRAO 140 Foot and 12 Meter Telescopes**

In this project, the student will catalog and scientifically characterize the data archives of two retired NRAO single dish telescopes to investigate the tools and techniques of archival research. The NRAO 140 Foot Telescope was completed in the spring of 1965. Located in Green Bank, West Virginia, the telescope had its last observation run during the second quarter of 1999. The 12 Meter telescope is located on Kitt Peak, 50 miles west southwest of Tucson, Arizona, and was one of the pioneering instruments in detecting molecules in space. In 2000, the telescope was closed as an NRAO facility. However, it is currently operating on a temporary basis by Steward Observatory of the University of Arizona. Even though these telescopes are no longer operational, NRAO still has a wealth of data from these two instruments. This project involves creating a strategy for long-term data curation and access, and implementing as much of it as possible during the summer session, using software components already in existence for the NRAO Data Vault and additional software components, as needed, created by the student.

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**Charli Sakari, of Whitman College,  
worked with James Miller-Jones on**



## **Investigating the jets of Cygnus X-3**

Cygnus X-3 is one of the brightest X-ray binary sources in the sky, particularly during its giant outbursts, when it launches relativistic jets which are seen to evolve on timescales of days. The location of the core of the binary system has hitherto been uncertain, hindering the interpretation of the complex morphologies observed in VLBI observations of the jets. In this project, we have looked at twenty-three years of archival data on Cygnus X-3 in order to constrain the proper motion of the system. From that proper motion, we can now determine the position of the core at any given time. The radial velocity of the system is unknown, with different authors deriving very disparate estimates. Using our measured proper motion and a model of the Galactic potential, we have determined the three-dimensional space velocities for the full range of radial velocities proposed in the literature. We use these space velocities to examine Cygnus X-3's orbital trajectory in the Galaxy, finding a minimum peculiar velocity of 40km/s. This information can be used to help constrain whether the system received a natal kick, allowing us to explore the formation mechanism of the compact object. We also determined the possible current locations of the supernova in which the compact object was formed, but current surveys of supernova remnants and OB associations do not extend far enough from the Sun to allow us to definitively identify the birthplace of Cygnus X-3.

**Alexander Savello, of Emory University,  
worked with Robert Dickman on**



### **Kinematic study of Bok globule CB4**

Bob Dickman and summer student Alex Savello worked on an analysis of the velocity field of the small, starless Bok globule CB4. Working with Dr. D.C. Lis of Caltech, they completed acquisition of the data in July, and completed a fully-sampled, high velocity resolution map of the cloud in the J=3-2 transition of  $^{13}\text{CO}$  using the Caltech Submillimeter Observatory's 10m radio telescope on Mauna Kea. A map of the globule in the common  $^{12}\text{CO}$  isotopic species was also obtained, along with a high quality spectrum of  $\text{C}^{18}\text{O}$  near the cloud center. Savello completed reducing the data during his summer fellowship. The  $\text{C}^{18}\text{O}$  spectrum affirms the extremely quiescent nature of the gas motions within CB4, and indicates that the adiabatic Mach number is no larger than  $\sim 0.5$  in the globule's central regions. A systematic velocity gradient  $\sim 0.05 \text{ km s}^{-1} \text{ arcmin}^{-1}$  consistent with rotation is also present in the cloud. After removing this systematic component, the residual velocity field is found to be remarkably uniform over the cloud.

**Matthew Schenker, of Dartmouth College,  
worked with Jim Braatz on**



### **Mapping the Megamaser Disk in Mrk 1419**

Single-dish observations of the water vapor maser emission from the nucleus of Mrk 1419 reveal a spectrum characteristic of emission from an edge-on accretion disk. Sensitive VLBI observations of such disks can be used in conjunction with spectral line monitoring to determine an angular diameter distance to the host galaxy. The student will reduce a spectral line VLBI observation of the maser in this galaxy to map its structure, for the first time. This galaxy is one of the key sources for the Megamaser Cosmology Project.

**Evan Schneider, of Bryn Mawr College,  
worked with Scott Ransom on**



### **Searching for the Pulsar in SN1986J**

In 1986, a supernova went off in a relatively nearby galaxy and almost certainly produced a neutron star. Over the last 20 years, VLBI observations have shown the expansion of the supernova remnant, and recently, the appearance of what is possibly a pulsar wind nebula in its center. Two years ago we used the GBT to observe SN1986J for 16 hours in order to search for the very young pulsar. The project for this summer was to search these data using a local computer cluster in Charlottesville. Because of the nature of the data, a significant amount of work (involving programming and low-level data analysis) was required to clean the data of interference and other artifacts. Most of this cleaning was done using programs written in python. Once the data was cleaned, two different search methods were used to examine the data: both a singlepulse search, looking for large, extra-bright pulses; and a frequency search, looking for periodic pulses. Although nothing has been found yet, if we do find a pulsar, it will be by far the brightest, most distant, and youngest pulsar known.



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**Colin Slater, of Case Western Reserve University,  
worked with Toney Minter on**

### **Power Spectra of HI in the Outer Galaxy**

VLA data have been obtained for several lines of sight toward the outer part of our Galaxy. These data can be used to determine the HI power spectra properties in the outer galaxy. The Canadian Galactic Plane Survey data can also be used to get HI power spectra in the outer Galaxy also. From the HI power spectra the scale on which energy is input into the Interstellar Medium from stellar winds, Supernovae, Galactic rotation, etc. can be determined. It will also be possible to determine the amount of energy input into the turbulence in HI versus Galactic radius. This should allow the separation of the different energy injection processes so that we can identify the dominant process.



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**Anthony Woody, of West Virginia University Institute of Technology,  
worked with John Ford on**

### **A low EMI m&c interface for the K band Focal Plane Array Receiver**

The student would research options for interfacing the proposed K band focal plane array receiver to the monitor and control system. Research topics include characterizing the EMI profile of nano-power microcontrollers, A/D and D/A converters, PC board noise characteristics, and application of the results of this effort to a prototype design for the receiver.

## 6. RET Project Summaries

This section provides summaries of the 2008 RET projects in this summer's program.

### *2008 RET Participants*

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**Jeff Paradis of Rush-Henrietta High School (Rochester, NY)**

**worked with Ron Maddalena on**

#### **Atmospheric Refraction at 1 GHz Using the NRAO 43m Telescope**

The pointing algorithms for all radio telescopes calculate a correction for atmospheric refraction. No individual refraction model is universally regarded as the best and astronomical observatories several are currently using several different models (Crane, 1976; Von Horner, 1976, 1993; Maddalena, 1994; Brussaard and Waterson, 1995; Yan 1996). Although almost all models agree at elevations above 20 degrees, some of the more widely used models disagree by up to an arc minute near the horizon. Large radio telescopes that work at high frequencies and that can observe down to the horizon require pointing accuracies that are much higher than the differences between models. The NRAO Green Bank Telescope (GBT), e.g., requires arc-second accuracy at 5 deg elevation. Unlike optical telescopes, radio observations cannot take advantage of guide stars that can be used during observing to overcome limitations in refraction models and, thus, require predictions on how to calculate refraction with sufficient accuracy. A significant reason for the lack of a 'universal' and accurate model is the low accuracy of the observations used to test refraction models. Thus, a series of experiments was conducted with the NRAO 43-m telescope to measure atmospheric refraction at cm-wavelengths with accuracy sufficient to distinguish the competing theoretical models.

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**Sarah Streb of Salpointe Catholic High School (Tucson, AZ)**

**worked with Miller Goss on**

#### **Pulsar Astrometry with the VLA and VLBA -and- OH Zeeman Pairs in W49 with the VLBA**

The summer's first project created a catalog of in-beam calibrators in support of an on-going, multi-epoch project that is measuring parallaxes on a sample of pulsars with the VLA and the VLBA. The summer's second project studied OH maser Zeeman pairs in W49, a well-known and active region of star-formation in our Galaxy. Several Zeeman line pairs were identified and used to determine the line-of-sight magnetic field component, providing an accurate map of the W49 magnetic field and the maser scattering disk orientation.

**Diana Soehl of Robert Moses Middle School (North Babylon, NY)**

**worked with Glen Langston on**

### **Pre-Biotic Molecules Spur a WebQuest: The Amazing Molecule Race**

Data acquired at the Green Bank Telescope (GBT) was used to search for pre-biotic molecules in the Taurus Molecular Cloud. The entire summer RET research experience was used to design a WebQuest that allows students to learn about radio astronomy and scientific research. The WebQuest discusses questions such as “Did you ever wonder if life exists beyond Earth?” and describes how and why astronomers are working to discover molecules in space, including the most important molecules for life, such as amino acids. Students learn how this research can shape policy regarding future space missions, funding and technology development.

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**Santosh Madhavan of Lake Highland Prep. High School (Orlando, FL)**

**worked with Mark Claussen on**

### **VLA Archival Spectra of the Water Masers around the Young Stellar Object**

**IRAS 16293-2422**

Archival data of observations of the water masers around the YSO IRAS 16293-2422 was retrieved, calibrated and imaged, using the Astronomical Imaging Processing System (AIPS) for several epochs. Spectra were computed by using the clean components file for each spectral cube (each epoch). Spectra were compared among epochs, in addition to published data, in order to characterize the time variability of spectral features of the masers in this source at different Doppler-shifted velocities relative to the Local Standard of Rest. Concepts from this program that relate to the classroom include the formation of stars and planets; the determination of velocities based on Doppler shifts; the determination of mass using Newtonian concepts; and the ideas of interferometry in obtaining images from an array of radio telescopes.

## **7. Participation in the AAS 213th Meeting January 4-8, 2009**

Possibly all four of our RET participants will travel to Long Beach, CA, to attend the [213th Meeting](#) of the [American Astronomical Society](#) in January. The number of NRAO summer program participants, including REU and GRP students, has not yet been confirmed.

The deadline for submission of abstracts to the Long Beach meeting is October 1, 2008. The deadline for late submissions is December 1, 2008. We anticipate that the Abstracts will be available for review on the AAS schedule web page at <http://www.aas.org/meetings/aas213/schedule.php> by mid December 2008.