National Radio Astronomy Observatory
REU/RET Program Report: 2006

Overview

Summer Student Program

Twenty-three students participated in NRAO's 2006 Summer Student program, including 14 undergraduate students supported by the National Science Foundation (NSF) 's Research Experiences for Undergraduates (REU) program, four graduating senior supported by the NRAO Undergraduate Summer Student program , and five graduate students supported by the NRAO Graduate Summer Student program . This was the forty-seventh year of the NRAO Summer Research Program , which has graduated over 1003 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 107 applicants to the 2006 NRAO summer student program, of whom 48 (45%) were women and 9 (8 %) were under-represented minorities. The 14 REU positions were filled by 7 women (50%) and 7 men (50%). No REU positions were filled by an under-represented minority. In all, 23 summer students were hired, 12 women (52%) and 11 men (48%), and 2 (9 %) under-represented minorities. Ten students were assigned to Socorro (6 REU), seven to Charlottesville (4 REU), and six to Green Bank (4 REU). Fifteen of the student participants, including 9 of the REU students, will present posters on their research projects at the winter meeting of the American Astronomical Society on January 5-10, 2007 in Seattle, Washington.

Summer Teacher Program

The NRAO's RET program offers teachers both a research experience and, with its emphasis on carryover to the classroom, encourages and supports the concept of inquiry (i.e. research) based instruction. Three teachers participated in NRAO research programs during the summer of 2006, supported by the National Science Foundation (NSF)'s Research Experiences for Teachers (RET) program.

This was the seventh year of the RET program at the NRAO, although the NRAO has offered a variety of teacher workshops for nineteen years. In 2006, there were 12 applicants to the NRAO RET program from 10 states, of whom 4 (33 %) were women. Three RET appointments were made, all in Green Bank. Every two years, appointments are made in Socorro, the next being 2007. In future years, appointments are anticipated in Charlottesville as well. Similar to the REU students, a brief description of the teachers' projects are included later in this report. Three RETs will present posters on their research projects at the January 5-10, 2007 AAS Meeting.

Organization of Report

This report is organized as follows. In Section 1 we list *all* Summer 2005 program participants. We then separately describe the different activities students and teachers participated in at one of the three main NRAO sites: Charlottesville (Section 2), Green Bank (Section 3), and Socorro (Section 4). In the following two sections we present brief descriptions of the research projects completed by each REU student (Section 5) or RET teacher (Section 6). These descriptions are available on-line at http://www.nrao.edu/students/archive/projects.php, which includes links to the final written reports. Finally, in Section 7 we list all of the REU and RET summer projects which will be presented at the 209th meeting of the American Astronomical Society in Washington, D.C. (January 2007). Many of these presentations are expected to be published in astronomical journals in 2007-8.

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1. Table of 2006 NRAO Summer Program Participants

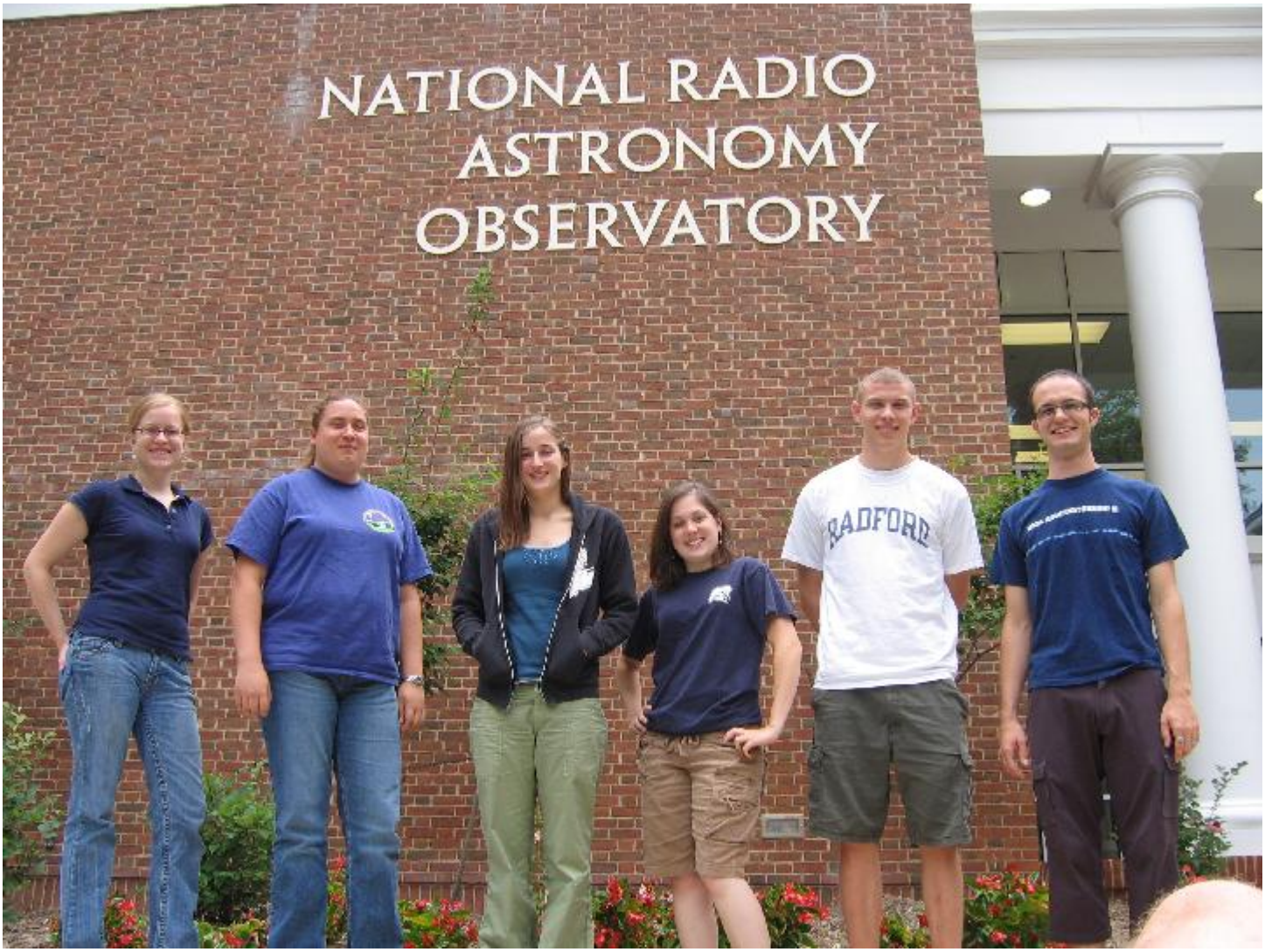
This table summarizes the student and teacher participants (name and school attending), research project (title, mentor, and assigned site), and the source of student support: NSF REU for students supported by the National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program, 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 26 summer student participants (14 REU, 4 uGRP, 5 GRP), and 3 summer teachers participants (RET).

2006 NRAO Summer Students/Mentors (N=26)					
Student	**School**	**Project**	**Mentors**	**Site**	**Program**
Wendy Bennett	Drake University	Free-Free Absorption of the Counterjet in NGC1275	Craig Walker	Soc	**NRAO uGRP**
Malynda Chizek	University of Iowa	Mars Radar Observations from 2003 Opposition	Bryan Butler	Soc	NSF REU
Abhirup Datta	New Mexico Tech	Simulation of Non-Isoplanatic Ionospheric Effects	Sanjay Bhatnagar	Soc	**NRAO GRP**
Claire Davy	Bryn Mawr College	L1448IRS3: The Structure and Evolution of a Class 0 Protostar	Jeff Mangum	CV	NSF REU
Robert Edmonds	University of New Mexico	Galactic Center SiO Maser Monitoring With the VLA	Lorant Sjouwerman	Soc	NSF REU
Michael Ford	Holton High School Holton, KS	HI Synthesis Observations of a Low Surface Brightness Galaxy	Karen O'Neil	GB	NSF RET
Lucille Frey	Case Western Reserve University	Finding and Studying Exotic Pulsars with the GBT	Scott Ransom	CV	NSF REU
Adam Ginsburg	Rice University	Searching for the Youngest Super-Star Clusters in Nearby Spiral Galaxies	David Meier	Soc	NSF REU
Nicole Gugliucci	University of Virginia	Exploring PAPER as a Wide-Field Imaging Instrument at 150 MHz	Richard Bradley	CV	**NRAO GRP**
Aaron (AJ) Heroux	University of Wisconsin - Whitewater	The Continuing Formation of the Milky Way	Jay Lockman	GB	NSF REU
Shelly Hynes	Louisiana School for Math, Science and the Arts Natchitoches, LA	Improving the Calibration of Data from the Green Bank Telescope	Ron Maddalena	GB	NSF RET
Jennifer Katz	Columbia University	Studies of Exotic Pulsars	Scott Ransom	CV	**NRAO GRP**

Student	School	Project	Mentors	Site	Program
Emily Martin	Wheaton College (MA)	Isotopic Abundances in Planetary Nebulae	Dana Balser	GB	NSF REU
Kushal Mehta	University of Maryland, Baltimore County	Archival HST study of the massive low surface brightness galaxy UGC 6614	Karen O'Neil	GB	NSF REU
Elisabeth (Betsy) Mills	Indiana University	The Bolocam 1.1 mm Galactic Plane Survey	James Aguirre	Soc	NSF REU
Manasseh Obi	Idaho State University	ALMA Front-End Bias Module Noise Analysis and Measurement	John Ford	GB	**NRAO uGRP**
Elizabeth Russell	Champion Charter School Taunton, MA	Mapping Pre-Biotic Molecules with the GBT	Glen Langston	GB	NSF RET
Destry Saul	UC Berkeley	Using a Modified Hough Transform to Measure Accelerations in AGN Accretion Disks	Jim Braatz	CV	NSF REU
Alok Singhal	University of Virginia	Understanding a Cosmic Yardstick	Rick Fisher	CV	**NRAO GRP**
Robert Stone	Radford University	Simulation of ALMA Observations: From Distant Galaxies to Protostellar and Protoplanetary Disks	Al Wootten	CV	NSF REU
Kristen Thomas	Mount Union College	OH Maser Emission In Bright-Rimmed Clouds	Larry Morgan	GB	**NRAO uGRP**
Rosa Torres Lopez	Centro de Radioastronomía y Astrofísica – UNAM	Parallexes and Proper Motions of Young Stars	Amy Mioduszewski	Soc	**NRAO GRP**
Timothy Weadon	West Virginia University	Green Bank Telescope (GBT): Refinement of the GBT Structural Model	Art Symmes	GB	NSF REU
Timothy Weinzirl	Drake University	Developing Applications for Exploration and Visualization of Interferometric Data	Kumar Golap & Wes Young	Soc	**NRAO uGRP**
Catherine Whiting	University of Iowa	VLA Imaging of Cygnus X-3	Amy Mioduszewski & Michael Rupen	Soc	NSF REU

Student	School	Project	Mentors	Site	Program
Laura Zschaechner	The University of Montana	Hydroxyl Masers as Tracers of Conditions in Supernova Remnants and Evolved Stars	Vincent L. Fish	Soc	NSF REU

2. Site Specific Activities: Charlottesville VA



The 2006 Summer Student program at NRAO/Charlottesville was under the direction of Jeff Mangum. There were seven students in the 2005 Summer Student Research Program at NRAO-Charlottesville, four of them under the NSF Research Experience for Undergraduates (NSF REU) program, and three under the NRAO Graduate Summer Student Program (NRAO GRP). The above photograph shows the Charlottesville summer students. The students from left to right are: Claire Davy (NSF REU), Lucy Frey (NSF REU), Jennifer Katz (NRAO GRP), Nicole Gugliucci (NRAO GRP), Robert (Lecky) Stone (NSF REU), and Destry Saul (NSF REU). Alok Singhal (NRAO GRP) is not shown.

The summer program included a series of introductory level lectures on aspects of astronomy, particularly radio astronomy and radio instrumentation. The lectures are listed in the CV Summer

Student Schedule below. The highlight of the summer was a student observing project using the Green Bank telescope (GBT), the world's largest steerable telescope.

The students did several projects on the GBT. They observed a protostellar core in the 2cm line of H2CO (formaldehyde) to search for evidence of a disk around the star, and to see how the H2CO region relates to other structures in the dark cloud. They also observed a few nearby galaxies in the 21cm line of HI to measure the redshift and rotational speed of the galaxies and search for asymmetries in their HI distribution. As a third project, they observed Galactic HI in absorption against a bright pulsar to determine the kinematic distance to the pulsar.

The students traveled to Green Bank, West Virginia, to participate in the GBT observations on June 26 & 27. The students arrived a day and a half early in order to meet members of the Green Bank staff, meet their student counterparts in Green Bank, and tour the NRAO facilities and telescopes, including the Green Bank telescope and the GBT visitors' center . In early July the Charlottesville students returned the favor and hosted a visit from the Green Bank summer participants (July 14). During this visit the students gave short presentations on their research topics to each other, took a tour of the NRAO Charlottesville facilities, including the NRAO Technology Center and the future site of the North American ALMA Science Center, and were entertained by the UVa astronomy faculty and graduate students.

At the end of the summer, the students gave a series of 15 minute talks on their projects during a lunch symposium in Charlottesville, and produced a short report describing their summer research. Four REU students and one GRP student will attend the AAS meeting in Seattle, Washington in January 2007 to present posters on their summer projects.

Charlottesville Summer 2006 Schedule

Day	Date	Time	Item	Location
Mon	May 22	10:00am	Start Date: Lucy Frey, Lecky Stone, Nicole Gugliucci	OIC
Tues	May 30	10:00am	Start Date: Claire Davy, Destry Saul	OIC
Thurs	June 1	1:00-2:30 pm	SS Lecture: Roy Norville & Jeff Mangum, ***Orientation***	AUD
Thurs	June 1	2:30-3:30 pm	Orientation Reception: Students and Staff	ER Foyer
Thurs	June 8	1:00-3:00 pm	SS Lecture : Marsha Bishop, ***Library Services***	CV230

Day	Date	Time	Item	Location
Mon	June 12	10:00 am	Start Date: Jennifer Katz	OIC
Tues	June 13	1:00-3:00 pm	SS Lecture : Jim Condon, ***Physics of Radio Sources***	CV230
Wed	June 14	12:00-1:00 pm	Movies from the Archives: "The Lift" [on building the 140 ft telescope] and "A Quarter Century of Science on the Meridian" [on building the 300 ft telescope]	CV230
Thurs	June 15	1:00-2:00 pm	SS Lecture: Ken Kellermann, ***An Overview of the History of Radio Astronomy***	CV230
Thurs	June 15	2:00-3:00 pm	SS Lecture: Ellen Bouten, ***The NRAO Historical Radio Astronomy Archive***	CV230
Tues	June 20	1:00-3:00 pm	SS Lecture : Mentors, ***GBT Observing Projects Discussion***	CV230
Thurs	June 22	12:00 noon	Student/Speaker Pizza Lunch	ER
Thurs	June 22	1:00-3:00 pm	SS Lecture: Fred Lo, ***Megamasers and Dark Energy***	CV230
Fri	June 23	1:00 pm	Depart CV for GB all day, CV Summer Student Trip to GB (Green Bank)	
Mon	June 26	5:30 pm-12:00 am	Observing, GBT	GB
Tues	June 27	12:00 am-7:00 am	Observing, GBT	GB
Thurs	June 29	1:30 pm-2:30 pm	SS Lecture: Mentors, ***GBT Observing Projects Reduction Discussion***	CV230

Day	Date	Time	Item	Location
Thurs	July 6	1:30 pm-3:00 pm	SS Lecture: Dave Hogg, ***Normal Galaxies***	CV230
Fri	July 7	2:00 pm-3:30 pm	UVa/NRAO Extragalactic group. Lecture by J. Hibbard on Ultracompact Blue Dwarfs.	UVa Colloquium Room, UVa Astronomy
Sat	July 8	12:00noon-4:00 pm	CV Picnic	McIntire Park
Tues	July 11	1:00 pm-3:00 pm	SS Lecture: Al Wootten, ***Molecules, Molecular Emission, and ALMA***	CV230
Fri	July 14	All Day	GB Summer Students Visit CV	
Fri	July 14	12:00 Noon	Student Speaker Lunch	CV311
Fri	July 14	1:30 pm-3:00 pm	SS Lecture: Mentors, ***Overview of Student Projects***	CV311
Tues	July 18	1:00 pm-3:00 pm	SS Lecture: Scott Ransom, ***Pulsars***	CV230
Thurs	July 20	1:30 pm-3:00 pm	SS Lecture: Jeff Mangum, ***Planetary Astrophysics and Star Formation***	CV230
Thurs	July 27	1:30 pm-3:00 pm	SS Lecture: Jim Braatz, ***AGN***	CV230
Tues	Aug 1	1:30 pm-3:00 pm	SS Lecture: John Hibbard, ***Galaxy Evolution***	CV230
Thurs	Aug 3	1:30 pm-3:00 pm	SS Lecture: Mark Adams, **Astronomy EPO Programs**	CV230
Fri	Aug 4	12:15 pm-1:15 pm	Lunch Talk (REU Presentation by Nicole Gugliucci)	CV230
Sat	Aug 5	5:00 pm-10:00 pm	GB Picnic	GB Recreation Area
Tues	Aug 8	12:15-1:15 pm	Lunch Talk (REU Presentation by Claire Davy and Destry Saul)	CV230

Day	Date	Time	Item	Location
Wed	Aug 9	12:15 pm-1:15 pm	Lunch Talk (REU Presentations by Jennifer Katz, Lucy Frey, and Lecky Stone)	CV230
Fri	Aug 11		Last Day: Claire Davy, Destry Saul, Lucy Frey	
Fri	Aug 18		Last Day: Jennifer Katz	
Sat	Aug 19		Last Day: Lecky Stone	

3. Site Specific Activities: Green Bank, WV

The 2006 REU/RET program at NRAO Green Bank was under the direction of Toney Minter and Sue Anne Heatherly. There were six students and three teachers in the 2006 Summer Research Program at NRAO-GB. Four students were supported by the NSF Research Experience for Undergraduates (NSF REU), and two of the students were supported by the NRAO Undergraduate Summer Student Program (NRAO uGRP). The three teachers were supported by the Research Experience for Teachers Program (RET). The photograph above shows several of the summer students standing with the Green Bank Telescope in the background. From left to right are Emily Martin (NSF REU), Kushal Mehta (NSF REU), Kristen Thomas (NRAO uGRP), A.J. Heroux (NSF REU), and T.J. Weadon (NSF REU). Not pictured is Manasseh Obi (NRAO uGRP).

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 the NASA Goddard/NRAO teacher workshop, a Chautauqua Short Course on Astronomy, the Society of Amateur Radio Astronomers (SARA) meeting and the Mid Atlantic Astronomical Society Star Party. There was also a weekly Science Lunch with the students every Thursday and regular 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. In mid-July the Green Bank summer participants traveled to Charlottesville to meet their counterparts. During this visit the students gave short presentations on their research topics to each other and took a tour of the NRAO Charlottesville facilities, including the NRAO Technology Center and the future site of the North American ALMA Science Center.

During the summer, the Green Bank students conducted their own observational projects on the GBT: mapping the OH around the large atomic/molecular cloud G28.07+0.05 and searching for HI associated with MIRA variables. At the end of the summer, the students gave the staff a one day seminar where they presented the results of their summer research projects. They also produced a short report describing this work. Four of the students (REU), and three RET participants will attend the AAS meeting in Seattle, Washington in January 2007 to present posters on their summer research projects.

Green Bank Summer 2006 Schedule

Day	Date	Time	Item	Location
Mon	May 22	9:00 am	First Official Start Date: Kristen Thomas, Tim Weadon II	
Thurs	May 25	12:00 noon	Science Lunch	
Tues-Sun	May 30-June 4	8:00 am-6:00 pm	Chautaugua 2006	Science Center
Tues	May 30	9:00 am	Second Official Start Date: Aaron Heroux	
Mon	June 5	9:00 am	Third Official Start Date: Emily Martin, Kushal Mehta	
Tues	June 6	10:00 am	Summer Student Orientation [Mandatory]	Jansky Auditorium
Tues	June 6	1:30 pm	Lecture: Gary Anderson, ***The History of Radio***	Jansky Auditorium
Tues	June 6	3:00 pm	GBT Tour	Meet in Basement

Day	Date	Time	Item	Location
Thurs	June 8	9:00 am	Start Date: Manasseh Obi	
Thurs	June 8	12:00 noon	Science Lunch	
Thurs	June 8	1:30 pm	Lecture: Sue Ann Heatherly, ***How To Use the 40 Foot Telescope***	Science Center
Mon	June 12	9:00 am	New Employee Safety Meeting [Mandatory]	GB137
Tues	June 13	1:30 pm	Lecture: Jay Lockman, ***Introduction to Radio Astronomy***	Jansky Auditorium
Wed	June 14	1:30 pm	Lecture: Roger Norrod, ***Receivers***	Jansky Auditorium
Thurs	June 15	12:00 noon	Science Lunch	
Sat-Tues	June 17-20	8:00 am-6:00 pm	Society of Amateur Radio Astronomers	Science Center
Tues	June 20	1:30 pm	Lecture: Dana Balser, ***GBT Performance***	Jansky Auditorium
Tues	June 27	9:00 am	Lecture: Karen O'Neil, ***HI in Galaxies***	Jansky Auditorium
Thurs	June 29	12:00 noon	Science Lunch	
Thurs	June 29	1:30 pm	Lecture: Toney Minter, ***Pulsars***	Jansky Auditorium
Fri	June 30	5:15 am-4:00 pm	GBT Observations	GBT Control Room
Tues	July 4	5:00 pm	Rabbit Patch 4th of July Picnic	
Wed	July 5	11:45 pm-12:00 am	GBT Observations	GBT Control Room

Day	Date	Time	Item	Location
Thurs	July 6	8:45 am	GBT Observations	GBT Control Room
Thurs	July 6	12:00 noon	Science Lunch	
Thurs	July 6	1:30 pm	Lecture: Frank Ghigo, ***VLBI***	Jansky Auditorium
Thurs	July 13	1:30 pm	Science Lunch	
Thurs	July 13	1:30 pm	Lecture: Carla Beaudet, ***RFI***	Jansky Auditorium
Fri	July 14	9:00 am	**CV Visit**	
Sun-Fri	July 16-21	8:00 am-6:00 pm	NASA/NRAO Joint Institute	Science Center
Tues	July 18	1:30 pm	Lecture: Jay Lockman, ***The Milky Way***	Jansky Auditorium
Thurs	July 20	12:00 noon	Science Lunch	
Thurs	July 20	1:30 pm	Lecture: Larry Morgan, ***The Interstellar Medium and Star Formation***	Jansky Auditorium
Mon	July 24	1:30 pm	Demo: Wes Sizemore, ***RFI Toy Demo***	Science Center Lobby
Tues	July 25	12:00 noon	Science Lunch	
Tues	July 25	1:30 pm	Lecture: Ron Maddalena, ***Weather Modeling for the GBT***	Jansky Auditorium
Thurs	July 27	12:00 noon	Science Lunch	
Thurs	July 27	1:30 pm	Lecture: Brian Mason, ***Cosmology***	Jansky Auditorium

Day	Date	Time	Item	Location
Fri	July 28	10:30 am	140 Foot Tour	
Sat	July 29		First Official End Date for Students	
Sun-Sat	July 30-Aug 12	8:00 am-5:00 pm	2nd Annual Governor's School of Math and Science	Science Center
Tues	Aug 1	1:30 pm	Summer Student Presentations	Jansky Auditorium
Thurs	Aug 3	12:00 pm	Science Lunch	
Fri	Aug 4		Second Official End Date for Students	
Tues	Aug 8	1:30 pm	Summer Student Presentations	Jansky Auditorium
Thurs	Aug 10	12:00 noon	Science Lunch	
Fri	Aug 11		Third Official End Date for Students	
Thurs	Aug 17	12:00 noon	Science Lunch	
Fri	Aug 18	3:30 pm	Colloquium: Garret Veschuur	Jansky Auditorium
Fri	Aug 18		Fourth Official End Date for Students	
Thurs	Aug 24	12:00 noon	Science Lunch	
Fri	Aug 25		Fifth Official End Date for Students	

4. Site Specific Activities: Socorro, NM

The 2006 REU program at NRAO Socorro was under the direction of Amy Mioduszewski. There were ten students in the 2006 Summer Student Research Program at NRAO Socorro. Six of the students participated via the NSF Research Experience for Undergraduates (NSF REU) program, two were supported by the NRAO Graduate Research Program (NRAO GRP), and two were supported by the NRAO Undergraduate Research Program (NRAO uGRP). The above photograph shows several students in front of the Array Operations Center. Back row from left are Timothy Weinzirl (NRAO uGRP), Laura Zschaechner (NSF REU), Wendy Bennett (NRAO uGRP), Catherine Whiting (NSF REU), Malynda Chizek (NSF REU), Robert Edmonds (NSF REU), Kyle Willett. Seated from left are Elisabeth Mills (NSF REU), David Sevilla, and Adam Ginsburg (NSF REU). Not shown are Abhirup Datta (NRAO GRP) and Claire Davy (NSF REU) and Rosa Torres Lopez (GRP).

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, including a "Wednesday Lunch" (free pizza for students!), a Tuesday Science Tea held in the upstairs lounge, weekly scientific colloquia, and ultimate frisbee on Tuesday and Thursday evenings. The students also attended the Ninth Synthesis Imaging Summer School, a week long school held at the University of New Mexico in Albuquerue. The group toured three observatories: the VLA, VLBA Pie Town station, and McDonald Observatory. On weekends the students gave public tours of the VLA.

The scientific highlight of the summer was the three student-led observational projects, one using the VLA and two using the VLBA. One group used the VLA to search for radio emission from a sample of nearby white dwarfs. Recent theoretical calculations suggested that magnetically active white dwarfs with planets in close orbits would produce radio emission. The second group used the VLBA to do high resolution imaging of a possible asymmetric gravitational lens system in order to determine whether it was actually a gravitational lens. If it was they would ask for follow up observations. The second VLBA project involved attempting to detect 1720 MHz masers at the galactic center. Detecting masers near the galactic center with the VLBA would be extremely valuable because it would allow high precision astrometry there.

At the end of the summer, the students gave a series of 15 minute talks on their projects during a lunch symposium, and produced a short report describing their summer research (sent under separate cover). Five REU students and one NRAO GRP students will attend the AAS Meeting in Seattle, Washington in January 2007. One NRAO GRP was sent to the SKA Calibration and Imaging Workshop in South Africa.

Socorro Summer 2006 Schedule

Weekly Events

Day	Date	Time	Item	Location
Tues		4:00 pm	Science Tea	Common Room
Wed		12:00 noon	Pizza Lunch	Auditorium
Sat-Sun	Jun 24-Aug 6	10:00 am-4:00 pm	Tours	VLA Site

Daily Calendar

Day	Date	Time	Item	Location
Tues	May 30		Summer Program Starts	AOC
Thurs	Jun 1		Earliest Check-in Date at Tech Apartments	
Day	**Date**	**Time**	**Item**	**Location**

Fri	Jun 2	4:00 pm	Student Reception + Dinner	Auditorium
Tues	Jun 6	1:00 pm	Safety Meeting	Auditorium
Fri	Jun 9	8:00 am	Apache Point Tour/NSO/Three Rivers/White Sands Field Trip	Meet at AOC
	Jun 13-20		Synthesis Imaging Workshop	UNM
Wed	Jun 21	2:00 pm	VLA Tour Meeting	Auditorium
Fri	Jun 23	10:00 am	VLA/VLBA Observing Project Meeting	Room 317
Fri	Jun 23	1:30 pm	Safety Meeting (E. Mills & R. Torres only)	Auditorium
Thurs	Jun 29	10:00 am	VLA/VLBA Observing Project TAC	Room 317
Thurs	Jun 29	11:00 am	Astronomical Masers - Mark Claussen	Auditorium
Mon	Jul 3		NRAO Holiday	
Tues	Jul 4		NRAO Holiday (Independence Day)	
Thurs	Jul 6	11:00 am	Pulsars - Walter Brisken	Auditorium
Thurs	Jul 6	4:00 pm	Aluminum Foil Hat Training Session	Auditorium
Thurs	Jul 6	5:00 pm	Barbecue	Sedillo Park
Tues	Jul 11	11:00 am	Ruby Payne-Scott: The First Woman Radio Astronomer - Miller Goss	Auditorium
Wed	Jul 12	3:00 pm	Cosmic Microwave Background - Steve Myers	Room 317
Fri	Jul 14	1:50 pm	Tour of IRIS/PASSCAL	Meet at AOC
Tue	Jul 18	11:00 am	Radio Galaxies - Jean Eilek	Auditorium
Thurs	Jul 20	4:00 pm	Pirate Day Workshop	Auditorium
Fri	Jul 21	9:50 am	Tour of Langmuir Lab	Meet at AOC
Tues	Jul 25	11:00 am	Solar System - Bryan Butler	Auditorium

Day	Date	Time	Item	Location
Thurs	Jul 27	11:00 am	Gamma Ray Bursts - Dale Frail	Auditorium
Fri	Jul 28	1:50 pm	Tour of EMRTC	Meet at AOC
Tues	Aug 1	11:00 am	Active Galactic Nuclei - Greg Taylor	Auditorium
Thurs	Aug 3	11:45 am	End-of-summer Lunch	Socorro Springs
Fri	Aug 4	12:00 noon	Summer Student Presentations: R. Edmonds, K. Willett, A. Ginsburg	Auditorium
Mon	Aug 7		Latest Check-Out Date at Tech Apartments	
Mon	Aug 7	12:00 noon	Summer Student Presentations: T. Weinzirl, L. Zschaechner	Auditorium
Wed	Aug 9	12:00 noon	Summer Student Presentations: D. Sevilla, W. Bennett, E. Mills	Auditorium
Fri	Aug 11	12:00 noon	Summer Student Presentations: M. Chizek, A. Datta, C. Whiting	Auditorium
Wed	Aug 30	12:00 noon	Summer Student Presentation: R. Torres	Auditorium

5. REU Project Summaries

This section lists short summaries of the projects for participants in the NRAO Summer Student program. The symbol to the right indicates students who were supported under the National Science Foundation (NSF)'s Research Experiences for Undergraduates (REU) program. All other students were supported under the NRAO Summer Student Research Assistantship Program.

Wendy Bennett, of Drake University,
worked with Craig Walker on

Free-Free Absorption of the Counterjet in NGC1275

NGC1275 (3C84) was observed at 6, 4, 2, and 1 cm with the VLBA, including using frequencies at the opposite ends of most of those bands to get the best possible spectra. The idea was to improve on what we were able to learn with previously published 1995 data (2000 Ap. J. 530, 233) and to look for changes. Wendy Bennett reduced these data

Malynda Chizek, of University of Iowa,
worked with Bryan Butler on

Mars Radar Observations from 2003 Opposition

Malynda worked on data taken with the joint Goldstone/VLA radar during the Mars opposition of 2003. We have observations on 4 dates at this time, and Malynda did the data reduction on the second of these dates, August 19 (last year's summer student, Tyson Mao, reduced the first day, August 11). She calibrated and self-calibrated the data (the self-calibration is tricky because of the frequency resolution in the experiment and the strong polarization response). She did the imaging, which is also tricky because of the interaction between frequency channels and spatial response ("doppler strips"). She combined the frequency channel maps into 39 final snapshot images, which display the rotation of radar reflectors which are tied to surface features across the disk of the planet. Significant results from this work are: - "Stealth" is confirmed - Strong return from Elysium Mons lava flows confirmed, along with structure seen in August 11 data - Elysium Mons "mini-Stealth" confirmed - Hellas as a "quasi-Stealth" confirmed - Bright returns from Tharsis and Olympus Mons volcanoes and their associated lava flows confirmed, including very interesting structure on the caldera of Olympus Mons - There is a significant enhancement from the South Polar Ice Cap, and not only from the seasonal cap (which was seen in earlier experiments), but also from the residual cap. This is similar to the August 11 results, but the structure is different, showing sublimation of the seasonal cap over the 8 days between observations. - "South Spot" bright reflector confirmed.

Abhirup Datta, of New Mexico Institute of Mining and Technology,
worked with Sanjay Bhatnagar on

Simulation of Non-Isoplanatic Ionospheric Effects

Radio interferometric observations at low frequencies and at high resolution and sensitivity are limited by the effects of non-isoplanatic ionosphere. Solving for ionospheric phase screen and correcting for it during image deconvolution is a challenging and scientifically useful problem to solve. First step towards that goal is to have software for realistic simulation of the ionospheric effects. Abhirup Datta worked on a theoretical understanding of the problem of non-isoplanatic ionosphere and developing realistic spatially and temporally varying ionospheric phase screens and using them to simulate interferometric observations. He also did work on the optimal parametrization of such phase screens.

Claire Davy, of Bryn Mawr College,
worked with Jeff Mangum on

L1448IRS3: The Structure and Evolution of a Class 0 Protostar

The L1448 molecular cloud possesses all of the classic signposts of recent star formation: collimated and uncollimated molecular outflow, H2O masers, compact radio continuum sources, emission from dense gas tracers such as H2CO and NH3, strong IRAS point source emission, and intense millimeter-wavelength dust continuum emission originating from both compact and extended sources. The region is generally separated into two components, L1448C and L1448N. Both are classified as Class 0 "protostars" (Bontemps et al. 1996), are sources of molecular outflow, and are associated with compact IRAS emission. The northern source of this pair, L1448N, is associated with the brightest of the IRAS point sources in the region, IRS3 (L_(bol) ~ 10 L_(sun)). High resolution images of the 2 and 6 cm continuum emission from L1448N found that this source was composed of two components: L1448N(A) (NOTE: L1448N(A) and L1448N(B) are referred to as L1448 IRS3A and3B, respectively, by Looney, Mundy, & Welch, following IAU standard nomenclature. We will use the Looney, Mundy, & Welch designations.) and L1448N(B) (Curiel et al. 1990; Barsony et al. 1998; Looney, Mundy, & Welch 2000). Tereby & Padgett 1997 and Looney, Mundy, & Welch also identify a third dust continuum source, L1448NW (called L1448 IRS3C by Looney, Mundy, & Welch) located ~20 arcsec to the NW of the IRS3A/B cores.

High resolution millimeter continuum images of L1448N (Terebey, Chandler, & Andre 1993; Terebey & Padgett 1997; Looney, Mundy, & Welch 2000) indicate that even though L1448 IRS3A is the dominant source of centimeter-wave continuum emission, L1448 IRS3B contributes most of the millimeter continuum emission. The C18O J=1-0 measurements of the L1448 IRS3 region by Terebey & Padgett indicate that the three L1448 IRS3 subcores are rotating at a rate of 100 km/s pc^(-1). Their measurements also indicate that the L1448 IRS3A/B subcores are collapsing. All three subcores appear to be Class 0 sources in various stages of evolution.

L1448 may also be one of a handful of star formation regions which exhibit hints of triggered star formation. The blueshifted lobe of the highly-collimated molecular outflow from L1448C coincides with

the L1448 IRS3 condensation. Measurements of the NH3 emission from this region by Curiel et al. (1999) indicate a potential interaction between this blueshifted lobe and L1448 IRS3, as evidenced by an increase in the local heating and velocity dispersion near IRS3. Curiel et al. cautioned that these physical affects could also be caused by heating from the young embedded source IRS3. High (<~ 9 arcsec, the spatial resolution of the Curiel et al. NH3 measurements) resolution measurements of the dense gas in the IRS3 region are needed to study the association between IRS3, the blueshifted lobe from L1448C, and the local heating and line broadening of the L1448 IRS3molecular core.

The Data

To provide the necessary information regarding the dense gas kinematic, spatial, and kinetic temperature structure within L1448 IRS3, we have imaged three lambda=1.4 mm transitions of H2CO with the BIMA millimeter-wave interferometer. These measurements have allowed us to:

- Determine the association between the dense gas and the envelope, disk, and core structures observed in millimeter continuum measurements;
- Distinguish between local heating and kinematic structure due to IRS3 and that due to a suspected interaction with the L1448C outflow; and
- Probe the kinematic and kinetic temperature structure over the entire L1448 IRS3 region. Terebey & Padgett (1997) presented a model including infall and rotation, based on high resolution interferometric observations in the C18O 1-0 line. H2CO is a superior tracer of dense gas, and owing to its many transitions constrains models very well.

Two of the three transitions of H2CO we have imaged have been observed toward L1448 IRS3 using the IRAM 30m telescope. These data were combined with the BIMA measurements to provide zero-spacings information to the analysis. As we have information on the physical structure of the H2CO emission from L1448 IRS3, we have modeled the formaldehyde excitation using a non-uniform microturbulent analysis, extending our early uniform LVG model (Mangum & Wootten 1993; Wootten & Mangum 1998). These measurements have allowed us to analyze the kinetic temperature structure on ~ 1000 AU size scales over the ~30 arcsec (~ 10,000 AU) extent of L1448 IRS3.

Robert Edmonds, of University of New Mexico,
worked with Lorant Sjouwerman on

Galactic Center SiO Maser Monitoring With the VLA

During 2004 May and 2006 February, 24 bright SiO masers in the direction of the Galactic center were monitored with the VLA. Robert Edmonds imaged and analyzed the 9 epochs and determined the SiO fluxes and light curves in the v=1 and v=2 lines. The findings were presented in a draft publication and a scientific presentation. Furthermore, a proposal was written (and a schedule prepared) to obtain the accurate positions for the two brightest masers. They are promising candidates to serve as 43 GHz VLBI calibrators in the Galactic center area, in particular for the new Japanese VERA array.

Lucille Frey, of Case Western Reserve University,
worked with Scott Ransom on

Finding and Studying Exotic Pulsars with the GBT

I present timing solutions for two binary and two isolated millisecond pulsars in globular cluster NGC6441. Pulsar NGC6441A was discovered during a 1.4 GHz search with the Parkes radio telescope (Possenti et al., 2001) and NGC6441B-D were discovered during a 2 GHz search with the Green Bank Telescope (Ransom et al., 2005). The spin down rate of NGC6441C was used to constrain the mass to light ratio of the cluster and show that the core mass-to-light ratio is ≥0.5 M sun/Lsun, typical for a globular cluster. The precession of periastron of NGC6441A due to general relativity was used to determine the total mass of the binary system, giving probable masses of 1.6 M sun for the pulsar and 0.8 M sun for the companion. The long tail in the probability distribution for the companion, however, leaves a possibility that the system instead contains two neutron stars.

Adam Ginsburg, of Rice University,
worked with David Meier on

Searching for the Youngest Super-Star Clusters in Nearby Spiral Galaxies

Adam Ginsburg joined in our ongoing research project imaging the small-scale structure of massive star forming regions in nearby galaxies. High resolution maps of young star formation with the VLA were used to identify and classify young, compact, optically-thick HII regions in nearby, spiral disks. Much work in this field has been done on dwarf starbursts that are free of extended disk synchrotron, but because of this confusion source and the generally weaker star formation in galactic disks, there have been essentially no successful detections of "supernebulae" associated with SSCs found in spiral disks. For this project Adam worked on the nearby star forming galaxy, Messier 66. We chose this galaxy because (1) it has a bright, gas-rich actively star forming disk, (2) has an untapped wealth of radio continuum data due to radio monitoring of 2 history supernovae, and (3) is an interaction induced strongly barred galaxy, permitting a study of the dynamical triggers of young SSCs. Adam searched through the VLA archive and found over 40 individual observations of M 66 (or its associated SN) in the VLA archive. He then calibrated each dataset (in the process becoming an expert with the AIPS software). The output resulted in deep radio continuum maps at L (> 3 hr on source), C (~15 hrs), X (~ 16 hrs) and U (2.4 hrs) including all array configurations. Adam generated maps at these frequencies, determining positions, sizes, fluxes and spectral indices of all compact radio sources seen in the highest resolution data. He found two or three sources that appear to be compact, massive HII regions associated with disk SSCs. These sources are brighter than any HII region complex in the disk of our Galaxy, having ionizing rates of ~10^52 s^-1, and have optically thick turnover frequencies at ~2 GHz. The sources are found exclusively at the bar end, suggesting they form from colliding gas clouds in the strong bar potential. Other sources were identified as SNR, but several compact sources remain unclassified having non-standard spectral indices. Adam and I plan to pursue the project further by proposing to get follow up observations, to improve L and U band sensitivities and to map the northern bar-arm region at U (outside the primary of the current U band pointings.

Nicole Gugliucci, of University of Virginia,
worked with Richard Bradley on

Exploring PAPER as a Wide-Field Imaging Instrument at 150 MHz

This project involves the development of the instrumentation for PAPER - the Precision Array to Probe the Epoch of Reionization. PAPER is a collaboration between my group and Don Backer's group at Berkeley. Our initial instrument is a 32-element, wide-field imaging array to be located in Green Bank and is scheduled for completion later this year. The student will work on the imaging of the first measurements with PAPER to better understand the systematics of our instrument and work toward suitable calibration measures. We expect to have sixteen elements of our array on location in Green Bank by May.

Aaron (AJ) Heroux, of University of Wisconsin - Whitewater,
worked with Jay Lockman on

The Continuing Formation of the Milky Way

AJ Heroux, from Univ. Wisconsin Whitewater, reduced GBT HI observations of Smith's Cloud, a high-velocity hydrogen cloud with peculiar kinematics. He organized the data, handled calibration, editing and mapping, and produced final image cubes. These data were compared to theoretical models of the interaction of clouds with the Galactic corona. We are continuing this work now that he is back at school, and expect to derive a trajectory for the cloud and information about it location and physical properties.

Jennifer Katz, of Columbia University,
worked with Scott Ransom on

Studies of Exotic Pulsars

The millisecond pulsar J1614-2230 was detected by XMM-Newton as an X-ray point source with faint extended emission in the direction opposite to the pulsar's proper motion. This observation reveals that J1614-2230 is powering a Pulsar Wind Nebula (PWN) that is interacting with the ISM. These PWN often form bow shocks when the pulsar has a high spatial velocity. In order to detect emission from the shock front, the system was observed using the Fan Mountain 40" telescope outside of Charlottesville, VA with H-alpha and red continuum filters. The red continuum data was subtracted from the H-alpha emission to isolate the shock. Unfortunately, with only 2 hours of integration time in each filter, the bow shock was not detected. However, even a non-detection can provide insights into properties of both the pulsar and the ISM in the vicinity and the possibility of continuing with more observing time remains.

Emily Martin, of Wheaton College (MA),
worked with Dana Balser on

Isotopic Abundances in Planetary Nebulae

Observations of molecular gas at 7 mm were made with the Green Bank Telescope (GBT) in a sample of planetary nebulae (PNe). PNe were selected to test stellar evolution models that include extra mixing processes by directly measuring the isotopic abundance ratios of processed material that has escaped the progenitor star. Moreover, these data are used to probe theories of chemical evolution through a sample of AGB stars, protoplanetary nebula, and young and evolved PNe. Emily Martin reduced and analyzed these data. She developed software programs to inspect and edit the raw Spectrometer data; calibrate the data taking into account atmospheric corrections; and to produce different averages of the data taken over 10 distinct epochs.

Kushal Mehta, of University of Maryland, Baltimore County,
worked with Karen O'Neil on

Archival HST study of the massive low surface brightness galaxy UGC 6614

The purpose of the project was to study the low surface brightness (LSB) galaxy UGC 6614. The project involved examining the optical data taken by the HST WFPC2 instrument and the HI data taken by the Very Large Array. The goal was to create optical and HI maps of this galaxy and combine them with a CO map of the galaxy obtained by Das, et al (2006) and analyze the star forming regions of the galaxy. The REU student's job was to fully reduce the HST data, and an RET reduced the archival VLA data. From the WFPC2 images, we clearly have shown UGC 6614 to have distinct spiral arms, with the CO detection lying in a region of the galaxy disk. Additionally, we detected 28 background galaxies and analyzed them with surface brightness and color profiles.

Elisabeth (Betsy) Mills, of Indiana University,
worked with James Aguirre on

The Bolocam 1.1 mm Galactic Plane Survey

The Bolocam Galactic Plane Survey (BGPS) is an ongoing project to survey the inner Galaxy in the northern hemisphere ($-5 < l < 90$, $-0.5 < b < 0.5$) and selected regions in the outer Galaxy in the 1.1 mm (270 GHz) continuum, with particular emphasis on the Center ($|l| < 5$) and the Molecular Ring ($20 < l < 50$). The Molecular Ring has been the subject of a recent FCRAO ^{13}CO(1-0) survey and the Spitzer-GLIMPSE Legacy survey. The goal of the BGPS is to provide a wide-area first-look inventory of cold molecular cores and condensations as a guide to future (sub) millimeter surveys, and to provide a statistical sample of pre- and proto-stellar high-mass cores. The main goal this summer was to make sense of the existing data in the Galactic Center and to compare it against other dust continuum and molecular line observations, and to begin developing the tools for cataloging cores and comparing them

to the ^{13}CO(1-0) data to obtain kinematic distances. The student completed a detailed study of several regions in the Galactic Center, including Sgr A* and its circumnuclear disk, the 50 and 20 km/s clouds, the Arches and GCM 0.25+0.01. These were compared with archival VLA, SCUBA (850 and 450 μm), SHARC-II (350 μm), MSX (8.3, 12.1 and 21.3 μm), and 2MASS continuum datasets, as well as molecular line observations from the literature. A first attempt was made to construct 4-color submillimeter SEDs from the Bolocam / SCUBA / SHARC-II data for the Galactic Center clouds. The student also developed software for source extraction in the less crowded fields away from the Center. This work will be included in a first paper on the BGPS, already in draft form and intended for submission this fall, and also several AAS posters at the January 2007 meeting.

Manasseh Obi, of Idaho State University,
worked with John Ford on

ALMA Front-End Bias Module Noise Analysis and Measurement

A model was developed to predict the noise characteristics of the bias module. Each component was modeled and the noise contribution from each component was included in the noise model. Tests were developed and conducted on prototypes of the module circuits to verify that the noise analysis accurately reflects the actual system characteristics.

Destry Saul, of UC Berkeley,
worked with Jim Braatz on

Using a Modified Hough Transform to Measure Accelerations in AGN Accretion Disks

Measuring the distance to a galaxy using the maser technique requires an analysis of disk dynamics based on VLBI maps of the disk, and separately, a measurement of the acceleration in the disk from single-dish monitoring observations. The student and I have developed a set of techniques to make an unbiased measurement of accelerations. The technique is a two-stepped approach: first maser peaks are identified through either a local maximum algorithm or a gaussian decomposition algorithm, and second the accelerations are measured using a modified Hough transform. The techniques were tested using synthetic data, and then applied to GBT observations of several galaxies.

Alok Singhal, of University of Virginia,
worked with Rick Fisher on

Understanding a Cosmic Yardstick

With this project the student developed a kinematic galaxy computer model for synthesizing neutral hydrogen (HI), 21-cm line profiles and two-dimensional HI maps for comparison with observed HI profiles and synthesis maps. The objective was to gain insight into the relationship between HI line profile width and the absolute brightness of galaxies. Although widely used as a cosmic scale yardstick, this relationship and its dependence on galaxy type and other properties are purely empirical. Theorists have suggested that the physical link between line width and brightness may have broader implication for understanding galaxy formation, evolution, and dynamics.

Robert Stone, of Radford University,
worked with Al Wootten on

Simulation of ALMA Observations: From Distant Galaxies to Protostellar and Protoplanetary Disks

ALMA's highest priority science goals are to image spectral lines from galaxies similar to the Milky Way at high redshift, and to image details of the structure of protostellar and protoplanetary disks. The student used existing tools in combination with ALMA performance measured in the lab and at the ALMA Test Facility, along with newly designed configurations of the antennas, to simulate ALMA's imaging abilities for the top science goals.

Kristen Thomas, of Mount Union College,
worked with Larry Morgan on

OH Maser Emission In Bright-Rimmed Clouds

Submillimetre continuum and molecular line observations of Bright-Rimmed Clouds (BRC) support the existence of intermediate to high-mass protostellar cores embedded within the clouds. These clouds may represent examples of Radiatively-Driven Implosion (RDI) in which star formation is induced by the propagation of photoionisation-induced shocks. The origin of these shocks being the high luminosity of nearby massive stars. Observations by Valdettaro et al (2005) have revealed a surprising lack of water maser emission from the BRC, water masers are associated with star-forming regions of all luminosities and so their non-detection appears contradictory. Observations with the Green Bank Telescope(GBT) have been made to search for OH masers, the most common, and often brightest of masing transitions. Detection of these masers may reveal details of an environment common to the BRC, whereas non-detection would appear to contradict other GBT observations of high-density Ammonia cores. The goal of ongoing research is to reconcile these contradictory data sets with a common theory of star formation in BRC incorporating, or discounting RDI.

Rosa Torres Lopez, of Centro de Radioastronomía y Astrofísica – UNAM,
worked with Amy Mioduszewski on

Parallexes and Proper Motions of Young Stars

The distances to low mass Pre-main Sequence (PMS) stars are poorly determined because they are heavily obscured. Hipparcos typically produced 10-20% errors in the two most heavily studied low mass star formation complexes, Taurus and rho Ophiuchus. Accurate distances are very important to calculating reasonable estimates of the fundamental parameters of these systems. Fortunately some low mass PMS stars emit non-thermal radiation that can be detected by the VLBA. This summer Rosa Torres Lopez reduced 18 VLBA astrometry observations of 3 stars in Taurus, Hubble 4, HDE283572 and TTau Sb. She then computed their parallaxes and proper motions producing distances with 0.5\% accuracy. She found that Hubble 4 and HDE283572 are moving ~6 times faster than TTau Sb and are approximately 20 pc closer to us. For the remainder of Rosa's thesis she will work on 6 more stars, 2 more in Taurus and 4 in rho Ophiuchus.

Timothy Weadon, of West Virginia University,
worked with Art Symmes on

Green Bank Telescope (GBT): Refinement of the GBT Structural Model

The current structural finite element analysis (FEA) model of the GBT is a three dimensional stick model whose deflection shows a 16 percent larger displacement than the measured values. Our goal is to create a three dimensional model which will better represent the reinforced joints of the actual structure and provide deflection values closer to those measured. As the majority of telescope deflection that influences pointing results from movement of the Feed Arm (see Figure 2), the initial refinements for the full GBT FEA model will concentrate on this area. Tim Weadon developed fourteen (14) 3D Inventor solid models of these joints and prepared six (6) corresponding NASTRAN FEA models. Tim compared the effective stiffness (i.e., deflection) of these refined FEA joint models to the stiffness of the equivalent FEA stick model. These refined stiffnesses will be used to develop nodal stiffness correction factors for the GBT stick model.

Timothy Weinzirl, of Drake University,
worked with Kumar Golap & Wes Young on

Developing Applications for Exploration and Visualization of Interferometric Data

Tim worked on two distinct mini projects for CASA. The first was "cleaning up" the CASA table browser written in JAVA. He added some additional functionality for doing arbitrary curve fitting and data plotting/visualization. The second mini-project was developing test scripts in python to evaluate the state of the current "build". These scripts involved using the new CASA framework to image and analyze test data to determine whether recent changes improve or degrade system performance.

Catherine Whiting, of University of Iowa,
worked with Amy Mioduszewski & Michael Rupen on

VLA Imaging of Cygnus X-3

Cygnus X-3 is a high-mass X-ray binary which experiences very large radio and X-ray flares. During these large flares it is known to eject relativistic jets which are seen on both mas (VLBA) and asec (VLA) scales. However these observations show a puzzling difference. The VLBA observations show a one-sided jet to the south and VLA observation show a 2 sided jet, dominant to the north. However these observations where always limited in time (a few observations) and selected to take place after different large flares. We designed a project to observe Cygnus X-3 approximately weekly over a 7 month time period with the VLA. During that time Cygnus X-3 (which is very active in general) experienced several 1 Jy flares and one 17 Jy flare. Catherine Whiting reduced approximately 17 of these observations allowing us to have an unbiased look at the development of jets in Cygnus X-3. She produced a movie that shows that the south is dominant sometimes and the north other times and it can change during an outburst. She also did some polarization calibration, showing for the first time that the emission from Cyg X-3 is about 5% polarized.

Laura Zschaechner, of The University of Montana,
worked with Vincent L. Fish on

Hydroxyl Masers as Tracers of Conditions in Supernova Remnants and Evolved Stars

Laura Zschaechner undertook three small but related projects involving OH masers over the course of the summer. Laura cross-correlated positions of known supernova remnants (SNRs) with the locations of 1612 MHz hydroxyl masers obtained from blind surveys in the literature. Models of collisional excitation that produce 1720 MHz maser emission also predict 1612 MHz maser emission in regions of higher density or higher column density. No correlations were found, suggesting that conditions suitable to produce a collisionally-excited 1612 MHz SNR maser do not exist in our Galaxy. Working with VLA data obtained by Dale Frail, Laura looked for 1720 MHz masers in the direction of several TeV sources. One mechanism believed to produce TeV emission at the surface of a supernova remnant would also be conducive to 1720 MHz OH maser production. No masers were found. Laura also reduced VLA data looking for 4750 and 4765 MHz excited-state emission from a variety of (mostly) outer Galaxy sources, primarily OH/IR stars. None of the OH/IR stars produced a detectable excited-state maser, consistent with previous, less sensitive surveys of a smaller sample of sources. However, Laura did detect excited-state OH emission toward two star forming regions. One of these regions, Mon R2, was the site of several spectacular excited-state maser flares that had disappeared into oblivion. The data clearly indicate that the maser has reappeared.

6. RET Project Summaries

This section lists short summaries of the projects for RET participants in the NRAO 2006 Summer Teacher Program.

High-Precision Calibration, Baselines and Nonlinearities with the GBT

[1]Hynes, S.F., [2]Maddalena, R.J, [3]Figura, C.
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The traditional methods for calibrating single-dish radio telescopes assume that the system gain is linear: detected power is taken to be proportional to the power incident on the antenna. The assumption is wrong at some low level and noticeably breaks down when observing an object that has a large dynamic range. The high sensitivity, clean beam, and very stable electronics of the Green Bank Telescope (GBT) allow us to detect nonlinearities that would be masked in most other radio telescopes. In particular, the signal processing components of the GBT produce an output power that exhibits at least a quadratic dependence on incident power. Our study indicates that measuring and compensating for the nonlinearity is rather trivial and improves calibration when observing objects with a high dynamic range. Once measured, the nonlinearity is shown to be stable over a typical observing run (~6-8 hours) with evidence of stability for up to several weeks.

We also investigated ways to improve spectral-line calibration and baseline shape when observing over a band that is many GHz wide, as is typical with many high frequency GBT projects. We have found that baselines are seriously degraded when using the traditional methods of calibration via scalar values for the system temperature and calibration noise diode that are averaged over the entire bandwidth of the observations. System calibration and baselines are shown to be substantially improved when we use noise diode and system temperature values that have a frequency resolution of a few MHz. We will be looking into ways of improving the signal-to-noise ratio of observations by combining these new calibration methods with data smoothing techniques.

Incorporating this research and the general topic of radio astronomy into the high school science classroom will also be discussed.

This work was funded in part by the NSF-RET program.

Cyanopolyyne Molecular Concentrations in the Taurus Molecular Cloud

Author Block: Elizabeth R. Russell[1]*, G. Langston*[2]
[1]*NRAO / Champion Charter Public School,* [2]*National Radio Astronomy Observatory.*

The Taurus Molecular Cloud (TMC) is considered pre-stellar meaning that it is not yet producing stars. TMC was first mapped by E. E. Barnard (1920), J. Khavtassi, (1960), and finally B. T. Lynds in 1962. In 1997, Bell et al. claimed to have found $HC_{11}N$ at a location in the TMC-1 now known as Bell. Scientist Glen Langston began his search for $HC_{13}N$ near that spot and called this new location TMCCP (**T**aurus **M**olecular **C**loud **C**yanopolyyne **P**eak) but was unable to find either $HC_{11}N$ or $HC_{13}N$.

Langston, of the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, has been studying the TMC since January of 2006 using the large Green Bank Telescope (GBT). Langston is searching for the largest molecule ever discovered in space, a molecular chain known as $HC_{13}N$, a cyanopolyyne. When Langston was unable to locate the molecule it was decided that it was time to determine what cyanopolyyne molecules were present in the TMC-1. Langston had confirmed the presence of HC_5N, HC_7N, and HC_9N but not $HC_{11}N$ or $HC_{13}N$.

In the summer of 2006 Research Experience for Teachers (RET), Elizabeth Russell worked at the NRAO in Green Bank, WV. Russell used the GBT to gather molecular concentrations of cyanopolyyne, HC_9N, in the Bell and TMCCP locations along with 23 additional locations surrounding the two sites in the TMC-1. This data was reduced using LINX and EMACs.
Funded through the NSF RET Program.

7. Poster Abstracts for the AAS 209th Meeting, January 5-10, 2007

Sixteen of the NRAO summer program participants, including ten of the REU students, two of the uGRP, and one of the GRP students, and three of the RET participants, will travel to Seattle, Washington to attend the 209th Meeting of the American Astronomical Society , from January 5-10, 2007. Below are the titles and abstracts of the posters they will present describing the results of their summer research. Many of the abstracts will specifically acknowledge the NSF REU program. In the interest of concision the acknowledgments are omitted here.

Session 030 YSO, Star Formation I
Poster, Sunday, 9:20 a.m.-6:30 p.m., January 7, 2007, Exhibit Hall 4

[030.11] Formaldehyde Emission From Protostellar Region L1448IRS3

Claire M. Davy *(Bryn Mawr College), J. Mangum (NRAO), A. Wootten (NRAO)*

Accurate measurements of temperature and density are essential in determining whether there are stars forming in a protostellar region and, if so, what the evolutionary state and physical characteristics of these protostars might be. Formaldehyde is a proven molecular probe for this purpose. Measurements of two formaldehyde transitions obtained at the BIMA interferometer and the IRAM 30 meter radio telescope have been used to derive the temperature structure within the L1448IRS3 protostellar region. A model of this temperature structure has been derived by constraining the physical conditions within L1448IRS3 using a monte carlo radiative transfer model to simulate the formaldehyde radiative transfer and molecular excitation in the cloud. With this kinetic temperature information we have gained a better understanding of the physical state of L1448IRS3.

Session 172 The Milky Way
Poster, Tuesday, 9:20 a.m. – 6:30 p.m., January 9, 2007, Exhibit Hall 4

[172.07] 43 GHz SiO Masers for Phase Calibration with VERA in the Galactic Center

Robert M. Edmonds *(University of New Mexico), L. Sjouwerman (NRAO), Y. Pihlstrom (University of New Mexico)*

We present 9 epochs of Very Large Array (VLA) observations of 24 relatively strong 43 GHz SiO (*J*=1->0, v=1 and v=2) maser emission in a sample of late-type stars located between 0.3 deg and 2.2 deg from the Galactic Center. The aim was to find suitable Galactic Center phase calibrators for the Japanese

"VLBI Exploration of Radio Astrometry" (VERA) network, which will perform sub-milli-arcsecond astrometry in the Galaxy and the Galactic Center. From our VLA monitoring we have found two sources with consistently strong emission. These will be suitable VERA 43 GHz phase calibrators if their emission is unresolved also on VERA baselines. This is currently being investigated with VLBA observations.

Session 159 Pulsars
Poster, Tuesday, 9:20 a.m. – 6:30 p.m., January 9, 2007, Exhibit Hall 4

[159.06] Timing Pulsars in Globular Cluster NGC6441

Lucille H. Frey (Case Western Reserve University), S. Ransom (NRAO)

We present timing solutions for two binary and two isolated millisecond pulsars in globular cluster NGC6441. Pulsar NGC6441A was discovered during a 1.4 GHz search with the Parkes radio telescope and NGC6441B-D were discovered during a 2 GHz search with the Green Bank Telescope. The spin down rate of NGC6441C was used to constrain the mass to light ratio of the cluster and show that the core mass-to-light ratio is typical for a globular cluster. Pulsar NGC6441A is a highly eccentric binary, allowing us to constrain the pulsar masses using relativistic effects. These constraints suggest a system of a 1.6 Msun pulsar and a 0.8 Msun companion with the possibility of a double neutron star within the errors.

Session 100 Star Clusters II and HST/ACS Survey of Galactic Globular Clusters
Poster, Monday, 9:20 a.m. – 6:30 p.m., January 8, 2007, Exhibit Hall 4

[100.03] Searching for the Young Super-Star Clusters in NGC 3627

Adam Ginsburg *(Rice University/NRAO)*

Searches for optically thick radio HII regions associated with young star clusters has been done primarily towards dwarf starbursts that are free of extended disk synchrotron. Because of this confusion source and the generally weaker star formation in galactic disks, little is known about "supernebulae" associated with SSCs in spiral disks. Deep, arcsecond resolution VLA maps at 20 cm - 2 cm of the disk of the nearby actively star forming spiral, NGC 3627, are presented, to study the distribution and properties of its radio HII regions. We discuss the locations, sizes, fluxes and spectral indices of the compact radio sources seen in the highest resolution data. Spectral indices are used to identify and classify young, compact, HII regions. Two to three sources that appear to be compact, massive HII regions associated with disk SSCs are found. These sources are brighter than any HII region complex in the disk of our Galaxy, having ionizing rates of ~10^{52} s^{-1}, and have optically thick turnover frequencies at ~2 GHz over 10 - 20 pc scales. The sources are found primarily at the ends of the bar, suggesting they form from colliding gas clouds in the strong bar potential. Other sources were identified as SNR, but several compact sources remain unclassified having non-standard spectral indices.

Session 172 The Milky Way
Poster, Tuesday, 9:20 a.m. – 6:30 p.m., January 9, 2007, Exhibit Hall 4

[172.13] Smith's Cloud (HVC) in 21 cm HI emission

A. J. Heroux *(University of Wisconsin – Whitewater)*

In studying the continuing formation of the Milky Way, we have used the Green Bank Telescope (GBT) of the NRAO to measure the 21 cm HI emission from a specific high velocity cloud known as "Smith's Cloud". This cloud is likely within the bounds of the galaxy and appears to be actively plunging into the disk. Our map covers an area about 10x14 degrees, with data taken every 3' over this range. Most of the emission is concentrated into a single large structure with an unusual cometary morphology, which displays signs of interaction between the cloud and the Galactic halo.
We will present an analysis of the cloud, along with information on possible FIR emission with information gained from the IRAS data, kinematics and likely orbits and paths for the origin and future of the cloud. This research was funded through an NSF REU Grant.

Session 085 Ground-Based Instrumentation II
Poster, Monday, 9:20 a.m. – 6:30 p.m., January 8, 2007, Exhibit Hall 4

[085.04] Research Experience for Teachers at Green Bank: High-Precision Calibration, Baselines and Nonlinearities with the GBT

Shelly Hynes *(Louisiana School for Math, Science and the Arts), R. J. Maddalena (NRAO), C. Figura (Wartburg College)*

The traditional methods for calibrating single-dish radio telescopes assume that the system gain is linear: detected power is taken to be proportional to the power incident on the antenna. The assumption is wrong at some low level and noticeably breaks down when observing an object that has a large dynamic range. The high sensitivity, clean beam, and very stable electronics of the Green Bank Telescope (GBT) allow us to detect nonlinearities that would be masked in most other radio telescopes. In particular, the signal processing components of the GBT produce an output power that exhibits at least a quadratic dependence on incident power. Our study indicates that measuring and compensating for the nonlinearity is rather trivial and improves calibration when observing objects with a high dynamic range. Once measured, the nonlinearity is shown to be stable over a typical observing run (~6-8 hours) with evidence of stability for up to several weeks.
We also investigated ways to improve spectral-line calibration and baseline shape when observing over a band that is many GHz wide, as is typical with many high frequency GBT projects. We have found that baselines are seriously degraded when using the traditional methods of calibration via scalar values for the system temperature and calibration noise diode that are averaged over the entire bandwidth of the observations. System calibration and baselines are shown to be substantially improved when we use noise diode and system temperature values that have a frequency resolution of a few MHz.
Incorporating this research and the general topic of radio astronomy into the high school science

classroom will also be discussed.

Session 004 A Potpourri of Internal Properties of Galaxies
Poster, Sunday, 9:20 a.m. – 6:30 p.m., January 7, 2007, Exhibit Hall 4

[004.11] Mapping a Low Surface Brightness Galaxy

Kushal T. Mehta *(University of Maryland, Baltimore County), K. O'Neil (NRAO)*

The purpose of this project is to study the low surface brightness (LSB) galaxy UGC 6614. The project involves examining the optical data taken by the HST WFPC2 instrument and combining it with HI data taken by the Very Large Array. The goal is to create optical and HI maps of this galaxy and combine them with a CO map of the galaxy obtained by Das, et al. (2006) and analyze the star forming regions of the galaxy. From the WFPC2 images, we can clearly see that UGC 6614 has distinct spiral arms, with the CO detection lying in a region of the galaxy disk. Additionally, we have detected 28 background galaxies and analyzed them with surface brightness and color profiles.

All of the data presented in this paper were obtained from the Multimission Archive at the Space Telescope Science Institute (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555.

Session 172 The Milky Way
Poster, Tuesday, 9:20 a.m. – 6:30 p.m., January 9, 2007, Exhibit Hall 4

[172.01] A Wide Area Map of The Galactic Center at 1.1 mm

Elisabeth A. Mills *(Indiana University), J. E. Aguirre (NRAO Jansky Fellow, CASA-University of Colorado), J. Bally (CASA-University of Colorado), J. Glenn (CASA-University of Colorado), M. L. Enoch (Caltech), N. J. Evans, II (University of Texas), J. Walawender (IfA-University of Hawaii)*

We present new images of two squares degrees towards the Galactic Center at 1.1 millimeters obtained with Bolocam at the CSO as a part of the Bolocam Galactic Plane Survey. Emission at this wavelength is compared with additional images from SHARC 2 at 350 microns and SCUBA at 450 and 850 microns as well as archival data from MSX and 2MASS. Infrared dark clouds observed in the MSX and 2MASS images are seen to be associated with strong emission at 1.1 mm. Dust emission spectra of several of these giant molecular clouds derived from their submillimeter and millimeter fluxes are also presented. In addition, we examine the circumnuclear disk of Sgr A* in detail.

Session 085 Ground-Based Instrumentation II
Poster, Monday, 9:20 a.m. – 6:30 p.m., January 8, 2007, Exhibit Hall 4

[085.02] Atacama Large Millimeter Array Low Noise Analysis

Manasseh O. Obi *(Idaho State University)*

The Atacama Large Millimeter Array (ALMA) is a millimeter wavelength telescope. It comprises about fifty 12- meter antennas located in Chile, South America. ALMA is an international astronomy facility. ALMA construction and operations are led on behalf of North America by the National Radio Astronomy Observatory (NRAO), operated by Associated Universities, Inc. (AUI). ALMA is scheduled to be completed and become fully operational by 2012. In the summer of 2006, the prototype of the front end cartridge bias board of the ALMA telescope was simulated and measured to ensure that the bias box met the required specification before it was mass produced, assembled and finally shipped off to Chile for installation.

It is critical that the ALMA amplifiers meet their required performance specifications under normal operating conditions. The Allan Variance stability, voltage and current noise densities are specified in the ALMA Front End Cartridge Bias Module Technical Specifications document number FEND-40.04.02.00-005-A-SPE. In order for the front-end cartridge to meet the required specifications, the bias voltage provided by the circuitry must be extremely stable and relatively free of noise. These specifications allow the given antenna resolution, imaging, array configuration, spatial resolution and sensitivity as stated in the ALMA scientific agreement to be met.

With my poster presentation, I intend to:
•Present the results of the observations and analysis I made at the NRAO site located in Green Bank, West Virginia and explain its relevance to the on-going ALMA project.
•Correlate the critical role of good engineering lay out and pre-design simulation of astronomical telescopes to their relative high performance based on my experience at Green Bank.
•Discuss the applications of intrinsic low noise amplifiers, filters, and miniature electrical components to Radio Astronomy.

Cyanopolyyne Molecular Concentrations in the Taurus Molecular Cloud

Author Block: Elizabeth R. Russell[1], G. Langston[2]
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The Taurus Molecular Cloud (TMC) is considered pre-stellar meaning that it is not yet producing stars. TMC was first mapped by E. E. Barnard (1920), J. Khavtassi, (1960), and finally B. T. Lynds in 1962. In 1997, Bell et al. claimed to have found $HC_{11}N$ at a location in the TMC-1 now known as Bell. Scientist Glen Langston began his search for $HC_{13}N$ near that spot and called this new location TMCCP (**T**aurus **M**olecular **C**loud **C**yanopolyyne **P**eak) but was unable to find either $HC_{11}N$ or $HC_{13}N$. Langston, of the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, has been studying the TMC since January of 2006 using the large Green Bank Telescope (GBT). Langston is searching for the largest molecule ever discovered in space, a molecular chain known as $HC_{13}N$, a cyanopolyyne. When Langston was unable to locate the molecule it was decided that it was time to determine what cyanopolyyne molecules were present in the TMC-1. Langston had confirmed the presence of HC_5N, HC_7N, and HC_9N but not $HC_{11}N$ or $HC_{13}N$.

In the summer of 2006 Research Experience for Teachers (RET), Elizabeth Russell worked at the NRAO in Green Bank, WV. Russell used the GBT to gather molecular concentrations of cyanopolyyne, HC_9N, in the Bell and TMCCP locations along with 23 additional locations surrounding the two sites in

the TMC-1. This data was reduced using LINX and EMACs.

Session 149 AGNs, QSOs and Active Galaxies 2
Poster, Tuesday, 9:20 a.m. – 6:30 p.m., January 9, 2007, Exhibit Hall 4

[149.18] Measuring Accelerations in Water Vapor Megamasers using the Hough Transform

Destry R. Saul *(UC Berkeley/NRAO), J. Braatz (NRAO)*

Circumnuclear water vapor megamasers in AGN can be used to determine distances to the host galaxies. The distance measurement technique combines an analysis of the rotation curve from VLBI data and a determination of the centripetal acceleration of systemic maser features available from monitoring. Here we present an unbiased method for measuring accelerations, based on the Hough transform. Our method involves first identifying the doppler velocities of individual spectral components at each epoch using either a local maximum algorithm or a gaussian component analysis. Next we search for secular drifts in the velocities using a tailored formulation of the Hough transform. We demonstrate the technique using both synthetic data and GBT monitoring data. This research was completed during a NSF Research Experience for Undergraduates.

Session 077 Clusters and Cosmology
Poster, Monday, 9:20 a.m. – 6:30 p.m., January 8, 2007, Exhibit Hall 4

[077.29] Understanding a Cosmic Yardstick - Simulating Neutral Hydrogen in Disk Galaxies

Alok Singhal (NRAO and University of Virginia), R. Fisher (NRAO), K. O'Neil (NRAO), E. Murphy (University of Virginia)

I am developing a 3-dimensional model of neutral hydrogen (HI) in disk galaxies to study galaxy kinematics and its effects on the Tully-Fisher (TF) relation. Many factors can introduce bias in the TF relation. The study of these factors is important because, if not corrected, these factors would result in a bias in distances determined from the TF relation. One of the important sources of bias lies in the estimation and correction of turbulent motions. The current practices result in over-correcting for turbulent velocities. This correction is larger for smaller galaxies, and thus turbulent motion corrections introduce errors as well as bias in the distances.

We simulated HI in UGC7321 and compared the simulated line profile and channel maps with the observations of the galaxy. Both show good agreement with the published results, with the caveat that the best-fit rotation curve and turbulent velocity are slightly different from the ones published in literature. One of the reasons for this discrepancy could be because of the lack of flaring/warping of HI in our model, while UGC7321 clearly shows signs of warping and flaring.

Session 076 Circumstellar Disk Models
Poster, Monday, 9:20 a.m. – 6:30 p.m., January 8, 2007, Exhibit Hall 4

[076.10] Simulating Protoplanetary and Debris Disk's for ALMA

Robert L. Stone *(Radford University and NRAO)*

Millimeter-wavelength interferometry offers a way to obtain high resolution information on the emission structures around nearby stars with debris disks such as Fomalhaut. ALMA will be able to attain a higher resolution than any other millimeter wavelength telescope to date. Observations of Fomalhaut's debris disk have already been made by single dish telescopes, as well as models, but the resolution of these can be fairly poor. I plan to discuss my model of Fomalhaut which simulates its debris disk at several different frequencies to show the level of detail that ALMA will achieve. I will also discuss how ALMA will be the forefront tool in discovering other systems similar to Fomalhaut in the future.

Session 030, YSO, Star Formation I
Poster, Sunday 9:20 a.m. – 6:30 p.m., January 7, 2007, Exhibit Hall 4

[030.07] A Search for OH Maser Emission In Bright-Rimmed Clouds

Kristen L. Thomas *(NRAO), L. K. Morgan (NRAO), J. S. Urquhart (University of Leeds, United Kingdom) , M. A. Thompson (The University of Hertfordshire, United Kingdom)*

We present a radio wavelength study of OH maser lines toward 46 bright-rimmed clouds in search of star formation activity. Observations were made using the National Radio Astronomy Observatory (NRAO) Green Bank Telescope (GBT) at frequencies of ν = 1612 MHz, 1665 MHz, 1667 MHz, and 1721 MHz. This study yielded a low detection rate of OH masers toward these regions. OH masers are efficient tracers of young star formation, so this result is puzzling if the scenario of induced intermediate- and high-mass star formation within these regions is correct. Further investigation is needed in order to determine the star forming nature of these bright-rimmed clouds.

Session 029 Variable Stars
Poster, Sunday, 9:20 a.m. – 6:30 p.m., January 7, 2007, Exhibit Hall 4

[029.15] VLA Imaging of Cygnus X-3 Jets at 8.5 GHz

Catherine A. Whiting *(University of Iowa/NRAO), M. Rupen (NRAO), A. Mioduszewski (NRAO)*

Cygnus X-3 is a famous relativistic jet source, which often undergoes large radio flares of up to 30 Janskys. Previous observations (Mioduszewski et al. 2001, ApJ, 553) of this source with the Very Long Baseline Array (VLBA) showed strong evidence for a one-sided southern jet, while Very Large Array (VLA) observations (Martí et al. 2006, A&A, 451) showed a double-sided jet, stronger to the north. This is puzzling, since other famous microquasar sources have always been consistent in showing highly symmetric, double-sided jets. To address this issue, multi-epoch VLA imaging before and after two

major flares of Cygnus X-3 at 8.5 GHz will be presented and compared with previous radio observations. After a flare of about one Jansky we observed a double-sided jet, dominated strongly to the south, but after a later flare of 17 Janskys we observed a double-sided jet, dominated to the north. We will discuss further the nature of the apparent changes in jet dominance and whether these variations are due to the source itself or its environment or some combination of both. We will also discuss jet speed, flux evolution, and the first detection of linear polarization in this source.

Session 101 Structure of Stellar Winds
Poster, Monday, 9:20 a.m. – 6:30 p.m., January 8, 2007, Exhibit Hall 4

[101.11] Observations of the 6 Centimeter Lines of OH in OH/IR Stars and Star Forming Regions

Laura K. Zschaechner *(University of Montana), V. L. Fish (NRAO), L. O. Sjouwerman (NRAO), Y. M. Pihlstrom (University of New Mexico), M. J. Claussen (NRAO)*

Recent observational and theoretical advances have given rise to ambiguities regarding the model for OH maser pumping in OH/IR stars. While ground-state OH lines have already been observed, the detection of excited-state OH lines would provide additional constraints on theoretical pumping models. To date, the only positive detections of excited-state OH emission in OH/IR stars have been a 4750 MHz maser in AU Gem and 6035 MHz maser emission in NML Cyg.

We report on Very Large Array observations of the 4750 and 4765 MHz OH lines toward 45 sources, most of which are OH/IR stars. All of the sources have previously exhibited ground-state maser emission. We do not detect excited-state emission in any evolved star at the 100 mJy level (5 σ). However, masers in the 4765 MHz transition are detected toward two star forming regions: Mon R2 and LDN 1084. Masers in each of these sources have been previously detected and have shown significant variability in the past. the 4765 MHz maser in Mon R2, which had exhibited two distinct flares, one of which surpassed 75 Jy before disappearing in 1998 December, appears to be undergoing a new flaring event.