National Radio Astronomy Observatory
REU/RET Program Report: 2012-2013

Overview

Summer Student Program

Summer 2012: Twenty-five students participated in the 2012 NRAO Summer Student program, including 18 undergraduate students supported by the National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program, and seven undergraduate and graduate students supported by the NRAO Undergraduate and Graduate Summer Student programs.

There were 167 applicants for the 2012 NRAO summer student program, of whom 68 (41%) were women and 17 (10%) were under-represented minorities. For the (25) summer students that accepted appointments, 15 were female (60%) and 10 were male (40%), while 3 (12%) were under-represented minorities. Six students were assigned to Socorro (3 REU), 11 to Charlottesville (10 REU), and 8 to Green Bank (5 REU).

Summer 2013: Twenty-five students are participating in the 2013 NRAO Summer Student program, including 20 undergraduate students supported by the National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program, and five undergraduate and graduate students supported by the NRAO Undergraduate and Graduate Summer Student programs. This is the fifty-fourth 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 185 applicants for the 2013 NRAO summer student program, of whom 57 (31%) were women and 23 (12%) were under-represented minorities. For the (25) summer students that accepted appointments, 12 were female (48%) and 13 were male (52%), while 2 (8%) were under-represented minorities. Seven students were assigned to Socorro (4 REU), 13 to Charlottesville (12 REU), and 5 to Green Bank (4 REU).

Summer Teacher Program

Summer 2012: Michelle Meijer is a physics teacher for the Hesperia Unified School District, in Hesperia, CA. She worked with Dr. Ron Maddalena and Dr. Dave Frayer to carry out GBT observations and data reduction for the 4mm spectral line survey of Orion-KL. She made measurements of the detected features and identified the line transitions using spectral line databases and the astronomical literature. Michelle presented her research at the 221st meeting of the American Astronomical Society. Michelle also created a curriculum for her high school students whereby they could explore the methodologies used by modern radio astronomers to determine the composition of molecular clouds. Students were expected to perform a procedure similar to that performed by the researchers to explore both how radio telescopes "see" the universe and to use the frequency spectra acquired to determine which molecules are present in the Orion KL Nebula.

Russell Kohrs is a high school astronomy teacher at Broadway High School in Broadway, Virginia. He worked with Dr. Glen Langston to commission the 20 Meter telescope at X-band and to develop user manuals for the Skynet Robotic Telescope Interface to the 20 Meter. He also developed several classroom activities that will enable students to use this telescope remotely.

Summer 2013: Chelen Johnson, a high school science teacher from The Breck School in Minneapolis, MI is working with Dr. Anthony Remijan on a research project to study astrochemistry using measurements from the Green Bank Telescope.

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1. 2012 NRAO Summer Program Participants

This table summarizes the student 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 25 summer student participants (18 REU, 4 uGRP, 3 GRP).

2012 NRAO Summer Students/Mentors (N=25)					
Student	**School**	**Project**	**Mentors**	**Site**	**Program**
Anna Ho	Massachusetts Institute of	Analyzing GBT pulsar data on	Scott Ransom and	CV	NSF REU

	Technology	the Globular Cluster Terzan 5	Paul Demorest		
Elizabeth McNany	Case Western Reserve University	Integrating Engineering and Astronomy Software	John Ford	GB	**NRAO uGRP**
Nathan Brunetti	University of Massachusetts Amherst	Correlating Physical and Chemical Evolution in Starless Cores	Rachel Friesen and Scott Schnee	CV	NSF REU
Trey Wenger	Boston University	The Galactic H II Region Discovery Survey	Dana Balser	CV	NSF REU
Stephen Pardy	Macalester College	Measuring the Multiscale Structure of the ISM in the Whirlpool Galaxy	Adam Leroy	CV	NSF REU
Molly Gallagher	Grinnell College	Probing Disk Assembly in the Extreme Outskirts of Galaxies	Juan Carlos Munoz-Mateos	CV	NSF REU
Arlo Osler	University of Kansas	Searching for Infall and Rotation toward Very Young Protostars	John Tobin	CV	NSF REU
Ryan Loomis	University of Virginia	Investigation of the Formation of Molecular Isomers Toward Astronomical Environments	Anthony Remijan	CV	NSF REU
Sarah Wood	University of Tennessee	HI in Dwarf Galaxies	Megan Johnson	GB	NSF REU
Christopher Thibodeau	Towson University	Green Bank Telescope Observations of a Milky Way Satellite	Jay Lockman	GB	NSF REU
Kristin Barclay	Harvard University	Receiver Characterization with a New Laboratory Spectrometer	John Ford	GB	NSF REU
Erin Schultz	University of	Modeling the Effects of	John Ford	GB	NSF REU

	Kansas	Multiple Interference Sources on Science with the Green Bank Telescope			
Laura Hosmer	University of Missouri-Columbia	Discovering the Star formation Regions in Galactic Center	Glen Langston	GB	NSF REU
Allison Towner	The University of Arizona	Star Formation in the Sagittarius Spiral Arm	Glen Langston	GB	**NRAO uGRP**
Trupti Ranka	Case Western Reserve University	Telescope Control System Experimental Analysis and Modeling	John Ford	GB	**NRAO GRP**
Rachel Smullen	University of Wyoming	Imaging the Spatial Density within Starburst Galaxies	Jeff Mangum	CV	NSF REU
Corey Bathurst	University of South Florida	Time Domain Radio Astronomy	Dale Frail	Soc	NSF REU
Kathryn Weil	Brandeis University	Polarization Monitoring Using the EVLA	Steve Myers, Debra Shepherd and Rick Perley	Soc	NSF REU
Zachary Edwards	Columbus State University	The X-factor of M82	Juergen Ott and Dave Meier	Soc	**NRAO uGRP**
Sinclaire Manning	Howard University	Dissecting Luminous Starburst Galaxy Mergers	Aaron Evans	CV	NSF REU
Amanda Walker-LaFollette	The University of Arizona	44 GHz methanol masers in the Galactic Center: Star Formation or Supernova and Cloud Collisions?	Lorant Sjouwerman and Ylva Pihlstrom	Soc	NSF REU
Traci Johnson	Carleton College	Toward a Unified Understanding of Radio Emission from Novae	Amy Mioduszewski and Michael Rupen	Soc	**NRAO uGRP**

Leah Morabito	University of Oklahoma	Ammonia in the inner disk of NGC 6946	Juergen Ott, Dave Meier and Emmanuel Momjian	Soc	**NRAO GRP**
Cameron Charness	Harvey Mudd College	Interstellar Chemistry	Anthony Remijan	CV	**NRAO GRP**
Seth Jackson	Howard University	An Investigation of Radiometer Calibration Issues Affecting Low Frequency Radio Telescopes	Richard Bradley	CV	NSF REU

2. Site Specific Activities: Charlottesville VA

The 2012 Summer Student program at NRAO/Charlottesville was conducted under the direction of Jeff Mangum. There were 11 students in the 2012 Summer Student Research Program at NRAO-Charlottesville, ten of them under the NSF Research Experience for Undergraduates (NSF REU) program and one under the NRAO Graduate Student Program (NRAO GRP). The photograph above shows the 2012 Charlottesville summer students and one Co-Op program participant.

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. In addition to lectures on radio astronomical science, engineering, and computing, the Charlottesville Summer Students were given a tour of the NRAO Technology Center (NTC). The Charlottesville Summer Students also visited NRAO Green Bank and toured the Green Bank facilities, including the Green Bank Telescope (GBT).

In collaboration with the NRAO Socorro summer students the Charlottesville summer students formulated, setup, and executed three science experiments using the Very Large Array (VLA). This aspect of the NRAO summer student program teaches students how to design and carry out a research experiment within a collaborative environment. The Charlottesville summer students then travelled to NRAO Socorro to work on reduction and analysis of the data from these experiments. One of these experiments even produced an interesting and previously unknown object near the Arp240 galaxy merger system. The students submitted a follow-up proposal to re-observe this object to investigate its spectral energy distribution and time variability. The analysis of these data continues.

At the end of the summer, each of the students gave a 15-minute talk to the NRAO staff describing the results from their summer research projects during several lunch symposia in Charlottesville. Each of the students was also encouraged to produce a short report describing their summer research.

3. Site Specific Activities: Green Bank, WV

The 2012 REU/RET program at NRAO Green Bank was under the direction of David Frayer. There were eight students in the 2012 Summer Research Program at NRAO Green Bank as well as two teachers who were supported by the RET program and carried out research with the students. Five students were supported by the NSF Research Experience for Undergraduates (NSF REU), two students were supported by the NRAO Undergraduate Summer Program (NRAO uGRP), and one student by the NRAO Graduate Summer Program (NRAO GRP). Pictured above are the NRAO Green Bank summer students. There was a special set of lectures based on radio astronomy and techniques given to the students by scientists and engineers on the Green Bank staff. The summer students participated to varying degrees in the Chautauqua Summer School, the Space Race Rumpus (Cycling and music festival), and the West Virginia Governor's School for Math and Science. The summer students visited the NRAO Central Development Lab in Charlottesville and presented their work to the Charlottesville summer students. At the end of the summer, each student gave a 15 minute talk where they presented the results of their summer research project to the Green Bank staff. Each student was also encouraged to write a short report describing the results of their summer research.

4. Site Specific Activities: Socorro, NM

The 2012 REU program at NRAO Socorro was under the direction of Amy Mioduszewski. There were six students participating in the 2012 Summer Research Program at NRAO Socorro. Three of the students participated via the NSF Research Experience for Undergraduates (NSF REU) program, two were supported by the NRAO Undergraduate Summer Program and one was supported by the NRAO Graduate Research Program (NRAO GRP). Pictured above are the six summer students. The Socorro summer students had a variety of activities to take part in, which included "Wednesday Lunch" (free pizza for students!) with scientific talks and Tuesday Science Tea held in the Domenici Science Operations Center (DSOC) upstairs lounge. The group also toured the Very Large Array (VLA). The students 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. Five of the students participated in the 13th Synthesis Imaging Workshop, an eight day workshop held at the beginning of the summer.

The scientific highlight of the summer was the three student-led observational projects, two using the VLA and the other using the VLBA. For the first time this year, the VLA/VLBA summer student observing project was done jointly with the NRAO summer students in Charlottesville. At the end of the summer, each student gave a 15 minute talk on their research project to the NRAO Socorro staff. Each student was also encouraged to produce a short report describing their summer research.

5. REU Project Summaries

The NSF logo indicates students who were supported under the National Science Foundation (NSF) Research Experiences for Undergraduates (REU) and Teachers (RET) 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.

Kristin Barclay, of Harvard University,
worked with John Ford on

Receiver Characterization with a New Laboratory Spectrometer

Under the direction and guidance of NRAO engineering and science staff, the student will design an experiment, assemble the necessary equipment, and use the experimental setup to characterize a radio astronomy receiver to be used on a telescope at Green Bank. This project requires a student with interest in radio astronomy instrumentation.

Corey Bathurst, of University of South Florida,
worked with Dale Frail on

Time Domain Radio Astronomy

The dynamic radio sky is seen as a frontier area in astrophysics, ripe for discovery. Radio observations offer a unique view of cosmic phenomena. They probe the interaction of fast outflows with the surrounding medium and the locations of strong magnetic fields and relativistic particles, leading to the discovery of exotic phenomena such as gamma-ray bursts, flaring brown dwarfs, tidal disruption events and supernova. The student will reduce VLA data from one or more transient projects in blind surveys for transients and studies of specific transients. As a side project, the student may also participate in imaging simulations for a planed future enhancement of the Very Large Array.

Nathan Brunetti, of University of Massachusetts Amherst,
worked with Rachel Friesen and Scott Schnee on

Correlating Physical and Chemical Evolution in Starless Cores

As starless cores evolve to become protostars, they undergo chemical and physical changes. Chemically, the abundance of molecules with deuterium increases relative to the "standard" version of the molecule with hydrogen. Physically, the core starts to collapse, and the infall motions can be detected with millimeter-band spectroscopy. We have collected HCO+ (3-2) spectral towards a sample of starless cores using the James Clerk Maxwell Telescope (JCMT). These cores all have previously measured (and published) [N2H+]/[N2D+] ratios, so the state of their chemical evolution is well-known. We propose to use the HCO+ (3-2) spectra to see if there is a correlation between the magnitude of the collapse rate and the deuterium enhancement of N2H+, as predicted by standard star formation models.

Cameron Charness, of Harvey Mudd College,
worked with Anthony Remijan on

Interstellar Chemistry

Interstellar Chemistry

Zachary Edwards, of Columbus State University,
worked with Juergen Ott and Dave Meier on

The X-factor of M82

H2 is the most abundant molecule in the universe and controls how gas collapses to form stars. To determine the mass, dynamics, density, temperature and other properties of H2 clouds is therefore indispensable for the understanding of star formation itself. But there's a problem: H2 is a symmetric molecule and does not emit rotational lines. This makes H2 "invisible" and one needs an indirect way to determine it's state. One way is to observe the next most abundant molecule: CO (but it is 104 times less abundant than H2!). A conversion factor X is then used to estimate how much H2 the CO corresponds to. The value of X has been highly controversial for many decades. Is it constant everywhere? If not, how big is the range of variation? Is it only good for cold or warm gas? What is the role of metallicity? The student will derive X in a unique fashion, via X-ray absorption. The target galaxy is a nearby starburst galaxy, M82, which sports a huge outflow perpendicular to the stellar and gaseous disk. The northern part of the outflow is behind the inclined gas disk of M82. The disk is thus absorbing some of the X-rays. The student will primarily be determining the absorption through X-ray imaging spectroscopy and model fitting using data from the Chandra X-ray space observatory. The student will compare the results to the absorbing column with the HI (data from the Very Large Array) and CO (Pico Veleta and CARMA) emission of the disk itself. X-ray absorption is sensitive to both, H2 and HI, so one can subtract the HI from the absorption then derive X via a comparison with the CO.

Molly Gallagher, of Grinnell College,
worked with Juan Carlos Munoz-Mateos on

Probing Disk Assembly in the Extreme Outskirts of Galaxies

One of the most surprising and unexpected findings of the GALEX space telescope, as a far as galaxy evolution is concerned, was the discovery of extended UV emission at considerably large radii around many galaxies -- the so-called extended UV disks (XUV). Star formation in these extreme environments (low HI density, close to primordial abundances, long timescales) constitutes an interesting astrophysical problem by itself. But this phenomenon is also relevant within a much broader picture of galaxy evolution, as galactic outskirts are excellent laboratories to study the inside-out buildup of disks. For how long has this extended star formation activity been going on? Has it already assembled a measurable population of old stars in the outer disk? Will this significantly alter the overall mass of the galaxy? The student will address these issues by combining GALEX images for a sample of XUV disks with near-IR ones from the Spitzer Survey of Stellar Structure in Galaxies (S4G). S4G has obtained deep images at 3.6 and 4.5 microns for a sample of more than 2300 nearby galaxies. These observations are excellently suited for mapping old stars down to surface densities of just a few solar masses per square parsec. This S4G-GALEX syngergy should therefore allow us to gauge the actual importance of XUV disks in galaxy evolution. The student will measure the SFR and stellar mass in the outer regions of these galaxies to derive a characteristic formation timescale. He/she will also determine whether this star formation activiy - should it continue at a similar rate- might contribute nor not to a substantial fraction of the galaxy's total mass in the future.

Anna Ho, of Massachusetts Institute of Technology,
worked with Scott Ransom and Paul Demorest on

Analyzing GBT pulsar data on the Globular Cluster Terzan 5

There are 34 known pulsars in the globular cluster Terzan 5, the vast majority of which were discovered with the GBT. We will search several GUPPI observations of the cluster looking for new pulsars. In addition, we will combine data from 3 different receivers in order to measure the rotation measures for as many of the pulsars in the cluster as possible. We will compare these with the known dispersion measures in order to constrain the Galactic magnetic fields on 0.01 to several parsec scales.

Laura Hosmer, of University of Missouri-Columbia,
worked with Glen Langston on

Discovering the Star formation Regions in Galactic Center

The student will discover star forming regions in the galactic center based on Skynet 20m observations at 8 GHz, 43m observations at 330 MHz, plus archive ammonia observations from the GBT 18-26 GHz Array. The low frequency, 330 MHz, observations detect pulsars and supernova remnants. High frequency observations determine the locations of warm molecular gas. The Ammonia observations allow measurement of the temperature of the star forming regions. This project is important for understanding the process of star formation in our galaxy and is valuable to test the new capabilities of Skynet.

Seth Jackson, of Howard University,
worked with Richard Bradley on

An Investigation of Radiometer Calibration Issues Affecting Low Frequency Radio Telescopes

Traci Johnson, of Carleton College,
worked with Amy Mioduszewski and Michael Rupen on

Toward a Unified Understanding of Radio Emission from Novae

The most common energetic outburst in the universe, novae result when the accretion of matter onto a white dwarf in a binary from its companion star leads to a thermonuclear explosion. There is a long history of radio observations of nova but they have never been studied in a unified way. Also recent observations showed that the classic model for nova, the Hubble flow model, didn't fit the observations very well. The students project is to finish the comparison of these new data with past observations in detail, to understand whether these differences are fundamental, or simply a function of earlier and more consistent observation. The student will complete compiling all the radio observations of old novae.

Ryan Loomis, of University of Virginia,
worked with Anthony Remijan on

Investigation of the Formation of Molecular Isomers Toward Astronomical Environments

Molecular isomers are prevalent in astronomical environments and may play a role in determining the formation routes of molecules in space. Isomers contain the same constituent atoms yet have different structures. Recently, Lattelais et al. (2009, ApJ, 696, L133) investigated the relative abundances of molecular isomers in astronomical environments. Lattelais and colleagues suggested that the isomer with the lowest zero point bonding energy (i.e., the most stable isomer) should be the most abundant, and thus most easily detected in astronomical environments. In addition, they suggested that isomer abundance ratios are directly proportional to their energy differences. Finally, given the number of interstellar isomers detected in various astronomical environments, it would be trivial matter to verify this minimum energy principle with existing observations. However, it is well known that the excitation, and hence the measured abundance ratio, of simple isomers (e.g. HCN/HNC) is very dependent on the local environment and not purely determined by their relative bonding strength ratio (see e.g. Sarrasin et al. 2010, MNRAS, 404, 518 and references therein). Furthermore, the hypothesis of Lattelais et al. also does not consider the formation route of molecular species which should be very important in determining the abundances of complex organic species in astronomical environments. The project involves testing the theory by Lattelais and colleagues using isomers of $C_3 H_2 O$. $C_3 H_2 O$ forms three structural isomers; propadienione ($CH_2 CCO$), propynal (HCCCHO) and cyclopropenone ($c\text{-}C_3 H_2 O$). The research will consist of the analysis of GBT observations of both the TMC-1 and SgrB2N regions to investigate the relative abundance of each isomer and their relative excitations. In all, we believe this investigation will show that the chemical formation route to the production of astronomical species, especially complex organics, should be much more significant than the relative zero point bonding energies in establishing relative abundance ratios.

Sinclaire Manning, of Howard University,
worked with Aaron Evans on

Dissecting Luminous Starburst Galaxy Mergers

The Great Observatories All Sky LIRGs Survey, or GOALS, is a multi-wavelength space-based telescope campaign designed to assess the nature of star formation and supermassive black hole accretion in a complete sample of Luminous InfraRed Galaxies (LIRGs). The activity in these galaxies is triggered by gas-rich galaxy collisions - during the collisions, significant amounts of dust, produced by mass loss from newly-formed stars, enshrouds the central regions of these galaxies where > 90% of their total energy is generated. Understanding the role these galaxies play in terms of their star formation and black hole activity will ultimately have bearing on unraveling the nature of the infrared/submillimeter background radiation, which contains half of the light generated in the Universe since the Big Bang and is likely comprised of luminous infrared galaxies at cosmological distances. The student working with Professor Evans and the GOALS team will analyze one of the galaxies in the GOALS sample. The focus will be on analyzing the galaxy at one or more wavelengths to assess the nature of its star formation and black hole activity. The work will likely lead to a publication.

Elizabeth McNany, of Case Western Reserve University,
worked with John Ford on

Integrating Engineering and Astronomy Software

This project consists of understanding the function of engineering software used to characterize radio astronomy instrumentation, and designing software to implement similar functions in the radio astronomy data analysis packages at the GBT. The student will learn data reduction techniques and radio astronomy instrumentation details, and will come away with an understanding of the effect of radio astronomy instrumentation and data analysis on science. The student should be interested in melding the fields of physics and computer science.

Leah Morabito, of University of Oklahoma,
worked with Juergen Ott, Dave Meier and Emmanuel Momjian on

Ammonia in the inner disk of NGC 6946

Intense star formation and large quantities of high density gas seem to go hand in hand. Stars come from dense molecular gas, but the UV radiation, stellar wind and SNe associated with massive fundamentally alter the environment of their nursery on very short timescales. Understanding how exactly is vital to determine the long term evolution and efficiency with which galaxies convert gas to stars. Nearby galaxies (of which NGC 6946 is one) permit access to weak, but diagnostically important tracers, honed from decades of small-scale Galactic research, to be applied a much wider range of galactic star formation rates and environments. And without the geometrical complications of being stuck inside the disk. Ammonia (NH3) is an exceptionally easy-to-use and precise thermometer of dense gas. The overall brightness of the inversion lines constrain the amount of dense gas present and ratios between the different lines are sensitive to the gas temperature. In this project the student will reduce and map Jansky VLA imaging data of the (1,1) (2,2) transitions of NH3 (higher NH3 transitions and HC3N density tracers are available if time permits) to reveal changing molecular gas physical conditions across the nucleus and inner spiral arms of NGC 6946. The line emission will be compared to offline 20 GHz continuum emission to characterize the interplay between massive star formation and the structure of the molecular ISM on GMC scales over the inner 3.5 kpc2 in the star forming disk. Questions the project will pursue include: Does the fraction of dense gas change progressing from interarm regions through the spiral arms? Between the nucleus and the inner disk? With local star formation rate? What about gas temperature? What is the heating source in disks, dynamical or star formation? In regions where it is star formation, over what volume does star formation influence gas conditions.

Arlo Osler, of University of Kansas,
worked with John Tobin on

Searching for Infall and Rotation toward Very Young Protostars

Stars and planetary systems form as a result of gravitational collapse of a dense cloud of gas and dust. Protostars in the earliest phase of formation are still embedded within their natal cloud in the presence of infalling gas and the slow rotation of the cloud enables a proto-planetary disk to form around the protostar. In the past, infall has generally been probed with low-resolution, single-pointing molecular line observations and it is uncertain if other effects in the protostellar system are contributing to the infall signatures. The student will work on new (Jan 2012) HCO+(J=3-2) maps taken with the IRAM 30m telescope and will determine if the two-dimensional emission structure can be explained primarily by infall and rotation. To do this, the student will compare these data to molecular line radiative transfer models of spherical and asymmetric collapse to examine if consistent with infall or if other processes (i.e. outflow shocks) are masking the signature of infall. For the clear infall candidates, the infall radii, velocities, and radius of rotation will be determined via modeling as well.

Stephen Pardy, of Macalester College,
worked with Adam Leroy on

Measuring the Multiscale Structure of the ISM in the Whirlpool Galaxy

The project will involve measuring multiscale structure in the star-forming gas of M51, the "Whirlpool Galaxy." The data set is a first-of-it's-kind, 40 pc resolution 3-dimensional map of star-forming molecular gas that spans the whole inner part of this bright spiral galaxy. The project will involve adapting existing code to measure how the properties of the structures in the molecular change as a function of scale considered from 40 parsecs (traditionally considered a typical cloud size) up to a kiloparsec (a large part of the galaxy). The main tools will be using "tree diagrams" to consider how the structures associated with individual star-forming clumps change as we take a broader view of the surrounding material. These measurements will help us understand the basic organization of gas in star-forming galaxies, including identifying the scale at which gas becomes gravitationally bound and what can really be considered a discrete star-forming clouds. The application of this technique to galactic scales is new and only possible because of the fantastic new data.

Trupti Ranka, of Case Western Reserve University,
worked with John Ford on

Telescope Control System Experimental Analysis and Modeling

With the assistance and guidance of NRAO staff, the student will carry out research and modeling of control systems for the ALMA Nutator assembly. This project will require application of skills in control system analysis, and in extending the state of the art in control and modeling flexible mirrors.

Erin Schultz, of University of Kansas, worked with John Ford on

Modeling the Effects of Multiple Interference Sources on Science with the Green Bank Telescope

Under the guidance of the NRAO staff, the student will simulate the effects of multiple non-coherent interference sources on the electric field in the far field. This project requires a student with interest in propagation and electromagnetics.

Rachel Smullen, of University of Wyoming, worked with Jeff Mangum on

Imaging the Spatial Density within Starburst Galaxies

Studies of the distribution of Carbon Monoxide (CO) emission in external galaxies (cf. Young & Scoville (1991)) have pointed to the presence of large quantities of molecular material in these systems. These studies have yielded a detailed picture of the molecular mass in many external galaxies. But, because emission from the abundant CO molecule is generally dominated by radiative transfer effects, such as high optical depth, it is not a reliable monitor of the physical conditions, such as spatial density and kinetic temperature, quantities necessary to assess the possibility of star formation. Emission from less-abundant, higher-dipole moment molecules are better-suited to the task of deriving the spatial density and kinetic temperature of the dense gas in our and external galaxies. For this reason, emission line studies from a variety of molecules have been made toward mainly nearby galaxies (see Mauersberger & Henkel (1989) (CS), Gao & Solomon (2004a) (HCN), Nguyen-Q-Rieu et al. (1992) (HCO+), Mauersberger et al. (1990) and Meier & Turner (2005) (HC3N), Mauersberger et al. (2003) (NH3), or Henkel, Baan, & Mauersberger (1991) for a review). The most extensive sets of measurements of molecular line emission in external galaxies has been done using the J=1-0 transitions of CO (Helfer et al. 2003) and HCN (Gao & Solomon 2004a). Since the J=1-0 transitions of CO and HCN are good tracers of the more generally distributed and the denser gas, respectively, but do not provide comprehensive information about the individual physical conditions of the dense, potentially star-forming gas, another molecule must be observed for this purpose. Formaldehyde (H2CO) has proven to be a reliable density and kinetic temperature probe in Galactic molecular clouds. Existing measurements of the H2CO 1(10)-1(11) and 2(11)-2(12) emission in a wide variety of galaxies by Baan et al. (1986), Baan et al. (1990), Baan et al. (1993), and Araya et al. (2004) have mainly concentrated on measurements of the 1(10)-1(11) transition. One of our goals with the present study was to obtain a uniform set of measurements of both K-doublet transitions with which the physical conditions, specifically the spatial density, in the extragalactic context could be derived. Using the unique density selectivity of the K-doublet transitions of H2CO we have measured the spatial density in a sample of galaxies exhibiting starburst phenomena and/or high infrared luminosity. Results from the first phase of this work, which was a "pilot survey" of a sample of mainly nearby galaxies measured using the GBT (Mangum et al . (2008) has shown that H2CO is a reliable and accurate density probe for extragalactic environments where the kinetic temperature is known. An extension of this pilot survey has been completed, further defining the dense gas environment within a sample of 13 of the 56 starburst galaxies in our sample. The focus of this student project will be the analysis of recently acquired EVLA measurements of the H2CO 1(10)-1(11) and 2(11)-2(12) emission toward a sub-sample of our starburst galaxy ensemble. These data will allow for a characterization of not only the density within these starburst galaxies, but also the *spatial distribution* of the dense gas in these regions.

Christopher Thibodeau, of Towson University,
worked with Jay Lockman on

Green Bank Telescope Observations of a Milky Way Satellite

"Complex H" is an enigmatic hydrogen cloud that appears to be in a retrograde, inclined orbit about the Milky Way. It contains many millions of solar masses of hydrogen but has little evidence of star formation. The summer project would be to examine new GBT observations of Complex H to try to understand its history in more detail, and its eventual fate as it enters the Milky Way. The project would involve some observing, and some data reduction, but mostly analysis.

Allison Towner, of The University of Arizona,
worked with Glen Langston on

Star Formation in the Sagittarius Spiral Arm

The Sagittarius spiral Arm exhibits a number of star forming complexes, including W51. The student will map the region surrounding the W51 source, searching for pulsars and diffuse emission from supernova remnants. The Student will use the Skynet system to capture optical images to match with their 8 GHz images of the same region. This project is important for understanding the process of star formation in our galaxy and is valuable to test the new capabilities of Skynet.

Amanda Walker-LaFollette, of The University of Arizona,
worked with Lorant Sjouwerman and Ylva Pihlstrom on

44 GHz methanol masers in the Galactic Center: Star Formation or Supernova and Cloud Collisions?

A survey in the inner few arcminutes of the Galactic center has revealed a vast number of Class I methanol masers. Generally these masers are seen to occur at locations where protostar outflows collide with the surrounding molecular environment, and therefore are considered to pinpoint locations where new stars are being formed. The survey area includes two giant molecular clouds, at least two supernova remnants and the circumnuclear disk surrounding the supermassive black hole Sgr A*. Class I masers are generated by collisions.

Other than the possible protostars in the cloud cores, in the Galactic center region the masers are also seen at locations where the expanding supernova shells interact with the molecular clouds, and in regions where streams of matter from the clouds are suspected to bounce into the circumnuclear disk. The student will characterize the different origins of the masers, and investigate whether the masers found at the supernova/cloud interactions actually indicate regions of star formation or whether some Class I masers can exist where star formation does not occur. The survey consists of two mosaics at 36 and 44 GHz, taken with the EVLA in 2010 and 2011. The student will reduce some of the 36 GHz survey data as an exercise, but the 44 GHz survey data is ready to be analyzed, and constitutes a complete project if the 36 GHz survey data cannot be reduced before the end of the REU program.

Kathryn Weil, of Brandeis University,
worked with Steve Myers, Debra Shepherd and Rick Perley on

Polarization Monitoring Using the EVLA

Starting in 2000, NRAO has been conducting a polarization monitoring program with the VLA and now with the EVLA. On approximately monthly timescales, we observed a standard set of bright sources at CXKQ bands with the VLA, and all bands now with EVLA. The primary goal was to have a record of the polarization of secondary (variable) calibrators that could be used to bootstap calibration of VLBA and VLA observations that could not observe primary calibrators. This program has produced a large dataset http://www.vla.nrao.edu/astro/calib/polar/ which has in the past been mined to study varibility of flux density and polarization in some of these sources. The student will work on a project involving analyzing the epochs of the 2010-2012 EVLA monitoring data (project TPOL0003). The student will also develop the analysis pipeline that can be used by the observatory to process the data semi-automatically using the CASA package. There exist a set of CASA Python scripts written by S. Myers that can serve as prototypes. As an output of the pipeline, the student should be able to produce high-quality light curves for these sources, identifying and characterizing flares.

Trey Wenger, of Boston University,
worked with Dana Balser on

The Galactic H II Region Discovery Survey

Galactic H II regions are the formation sites of massive OB stars. Because the main sequence lifetimes of OB stars are only ~10's of millions of years, H II regions are zero age objects compared to the age of the Milky Way. They thus reveal the locations of current Galactic massive star formation. They are the archetypical tracers of Galactic spiral structure. Their chemical abundances, moreover, indicate the *current* state of the interstellar medium and reveal the elemental enrichment caused by the nuclear processing of many stellar generations. They provide unique and important probes of billions of years of Galactic chemical evolution. Despite enormous effort the census of Galactic H II regions is vastly incomplete. The HRDS team is doubling the number of known H II regions in the first and fourth Galactic quadrants using observations of radio recombination lines at cm-wavelengths. For each discovered nebula we are measuring its radial velocity, establishing its kinematic distance, and cataloging its physical properties. Our new nebulae allow us to probe entirely new zones of the Milky Way. The summer student will be a member of the HRDS team and work on projects that include GBT observing, data analysis, H II region modelling, etc.

Sarah Wood, of University of Tennessee,
worked with Megan Johnson on

HI in Dwarf Galaxies

The student will study the stellar velocities and velocity dispersions of the stars in DDO 46 and DDO 168 using optical spectra obtained previously with the KPNO 4-meter + Echelle spectrograph. They will be responsible for reducing these data and analyzing them. Then, the student will explore the HI content around DDO 46 and DDO 168 with the GBT. Together, we will analyze the data taken with the GBT to determine if tenuous HI emission can be seen around these gas rich dwarfs. These data will provide clues to the formation and evolutionary history of these tiny galaxies.

6. Participation in the AAS 221st Meeting January 9-13, 2013

Fifteen of the NRAO summer students travelled to Long Beach, CA, to attend and present the results from their summer research projects at the 221th meeting of the American Astronomical Society in January 2013. The following lists the summer student presentation session numbers and titles:

- **Nathan Brunetti**: 349.21. "Correlating Physical and Chemical Evolution in Starless Cores"
- **Zachary Edwards**: 349.11. "Determining the X-Factor of M82"
- **Molly Gallagher**: 251.04. "The Properties and Potential of XUV-Disks"
- **Anna Ho**: 154.11. "A New Method for Measuring the Rotation Measures of Millisecond Pulsars in the Globular Cluster Terzan 5"
- **Laura Hosmer**: 345.24. "Radio and Optical Telescopes for School Students and Professional Astronomers"
- **Ryan Loomis**: 352.10. "Broadband Screening for Interstellar Species: Additional Laboratory Measurements and Interstellar Detection of Ethanimine (CH_3CHNH) in Sgr B2(N) Using GBT PRIMOS Survey Data"
- **Sinclaire Manning**: 442.03 "Age-Dating Optically-Visible Star Clusters in Galaxy Merger NGC 5257/5258"
- **Arlo Osler**: 251.16. "Modeling the Infall of Gas onto Class 0 Protostars"
- **Stephen Pardy**: 146.20. "Plateau de Bure Arcsecond Whirlpool Survey (PAWS): Multiscale Analysis of the ISM in the Whirlpool Galaxy"
- **Rachel Smullen**: 157.07. "Imaging the Spatial Density Within Starburst Galaxies"
- **Allison Towner**: 349.05. "Physical Temperature Measurements of L1551"

- **Amanda Walker-LaFollette**: 254.07. “The Survey of 44GHZ Methanol Masers and Star Formation Towards the Galactic Center”
- **Katie Weil**: 240.04. “Polarization Monitoring Using the EVLA”
- **Trey Wenger**: 413.02. “The Green Bank Telescope H II Region Discovery Survey IV. Helium and Carbon Recombination Lines”
- **Sarah Wood**: 242.05. “Inside Out: The Stellar Kinematics and HI Map of DDO 46”