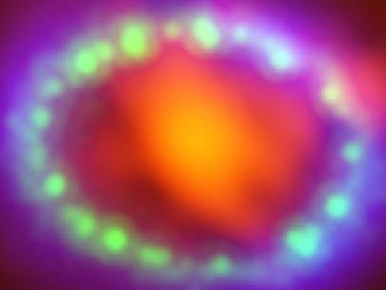


**10<sup>th</sup> Annual**  
**NRAO POSTDOCTORAL SYMPOSIUM**



**April 7 – 8, 2014**  
**National Radio Astronomy Observatory**  
**Charlottesville, Virginia**



## Monday, 7 April 2014

8:30	Registration	
9:00	Welcome	Tony Beasley
9:30	Comet ISON and the Demise of Comets	Michal Drahus
10:00	A GPU Accelerated Pulsar Search	Jintao Luo
10:30	Coffee Break	
11:00	Toward Understanding Proto-Planetary Disk and Binary Star Formation	John Tobin
11:30	The conditions in an extreme Galactic center cloud	Elisabeth Mills
12:00	Direct identification of PAHs with the GBT	Laura Perez
12:30	Lunch	
14:00	CHILES Con Pol: Probing galaxy evolution, the dark Universe, and cosmic magnetism with a deep 1000 hour Jansky VLA survey	Chris Hales
14:30	The making of T-RaMiSu	Huib Intema
15:00	Coffee Break	
15:30	Radio Diagnostics of the Inhomogeneous Intergalactic Medium	Brian Lacki
16:00	The radio universe as seen from Socorro	Walter Max-Moerbeck
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19:00	Dinner at Mellow Mushroom	

## Tuesday, 8 April 2014

- |       |   |                        |
|-------|---|------------------------|
| 9:00  | Dusty Star-Forming Galaxies at High Redshift                                      | Andrew Baker           |
| 10:00 | Coffee Break  |                        |
| 10:30 | Bridging the Gap: Connecting Galactic and Extragalactic Studies of Star Formation | Amanda Heiderman       |
| 11:00 | The GBT: A Mapping Machine for Dense, Star-Forming Gas in Nearby Galaxies         | Amanda Kepley          |
| 11:30 | Star Formation in Dwarf-Dwarf Mergers: Fueling Hierarchical Assembly              | Sabrina Stierwalt      |
| 12:00 | Finding tiny, gas-rich galaxies on the edge of the Local Group                    | Jennifer Donovan Meyer |
| 12:30 | Lunch with Scientific Staff   |                        |
| 14:00 | Revealing Massive Black Holes in Dwarf Galaxies with the VLA and Chandra          | Amy Reines             |
| 14:30 | Viewing galaxies in Faraday depth space   | Sui Ann Mao            |
| 15:00 | Coffee Break  |                        |
| 15:30 | Extended [CII] and [OI] emission from star forming galaxies at $z \sim 1.8$       | Drew Brisbin           |
| 16:00 | Resolved Studies of High-Redshift Submillimeter Galaxies                          | Jacqueline Hodge       |
| -     |   |                        |
| 19:00 | Dinner at Basil   |                        |

**Michal Drahus**

## **Comet ISON and the Demise of Comets**

Comet C/2012 S1 (ISON) was discovered on 21.1 Sep. 2012 UT, and subsequently identified as a recent escapee from the Oort cloud, having been stored in deep freeze since the formation of the solar system. ISON quickly attracted immense public interest owing to the extremely good visibility prospects: on 28.8 Nov. 2013 UT it was going graze the Sun at 0.0125 AU (i.e. less than one solar diameter above the photosphere), promising an unforgettable sight a couple weeks later. As it happens with comets, however, ISON chose its own way, and after passing perihelion was never seen again in the night sky. Instead, everyone around the world could witness the apparent dissipation of the comet's nucleus at the day of perihelion, thanks to the live broadcast from the NASA's solar space telescopes. I will discuss the "anatomy" of ISON's demise, including insightful data from millimeter spectroscopy, and show how it fits to the emerging view of the decay of comets.

**Jintao Luo**

## **A GPU Accelerated Pulsar Acceleration Search**

Orbital motions of pulsars in binary systems cause Doppler shifts on the received signal. This so-called 'acceleration' of such pulsars makes the observed pulsar spin frequency sweep over a range instead of turning out to be a single stationary frequency, hence decreases the sensitivity of observations. The technique of acceleration search has been developed to recover the pulsar signal from this effect. Acceleration search could be carried out in the time domain and the frequency domain.

In PRESTO, the Pulsar Exploration and Search TOolkit, the frequency domain acceleration search is adopted. We have been, and are being, working to accelerate this acceleration search with Nvidia GPUs. Compared to the CPU version, the GPU version has provided  $\sim 20\times$  speedups. And the higher speedup is expected from the future work.

**John Tobin**

## **Toward Understanding Proto-Planetary Disk and Binary Star Formation**

The formation of disks and binary systems is generally thought to begin early in the star formation process. However, there have not been sufficient numbers of young protostars (Class 0 and I phases) observed with high enough resolution to determine when and where most binaries form and whether or not large disks are common at early times. I will present several case studies examining the forming circumstellar disks and binary systems using a combination of ALMA, CARMA, SMA, VLA, and Gemini data. Finally, I will present initial results from a 264 hour Jansky VLA large program that has observed all protostars in the Perseus molecular cloud ( $N \sim 80$ ) with an ultimate spatial resolution of 15 AU. The results on the protostellar multiplicity frequency and separation distribution will significantly improve our understanding of the binary formation mechanisms and prevalence of close binaries and disks during the early stages of star formation.

**Elisabeth Mills**

**The conditions in an extreme Galactic center cloud**

Molecular gas properties in the central 500 parsecs of the Galaxy are markedly different from those in the Galactic disk. Galactic center gas clouds are characterized by large, turbulent line widths, high temperatures, and substantial densities. Perhaps as a result of these conditions, the rate of ongoing star formation in the center of our Galaxy appears to be abnormally low. I will present new results for one particular cloud in this region, "The Brick", which is sufficiently massive to form a star cluster but exhibits few signs of ongoing star formation. These results show that although the cloud is 'quiescent' in terms of star formation, in reality it is anything but- exhibiting uniformly elevated temperatures, new tracers of large-scale shocks, and strong velocity gradients, indicating the cloud is currently in a state of flux.

**Laura Perez**

## **Direct identification of PAHs with the GBT**

Polycyclic Aromatic Hydrocarbons (PAHs) are an abundant and important component of the interstellar medium (ISM). Not only they are the building blocks of larger interstellar dust grains but also mediate energetic and chemical process throughout the ISM. In addition, PAHs are thought to be the carrier for the diffuse interstellar bands in the visible and for the IR features between 3-20 microns. Furthermore, their rotational line emission is believed to be responsible for the anomalous microwave emission (AME) detected at frequencies near 30 GHz. Yet, not a single PAH has ever been directly identified, despite the significant role they play in a multitude of astrophysical processes. We are currently using the Green Bank Telescope to undertake a blind search for rotational line emission from PAHs, that could unambiguously identify specific PAHs in the ISM and finally settle this problem.

Since a vast number of different PAHs can be radiating in the ISM, a forest of rotational lines from small PAHs can easily produce a quasi-continuum - which is believed to be the dominant source of AME. Fortunately, PAHs in configurations that are quasi-symmetric (where for example a single carbon atom has been substituted by a nitrogen atom) have a characteristic spectra: a comb of evenly-spaced clusters of transitions (Ali-Haimoud, 2014). Using matched-filtering techniques we can extract the underlying comb pattern, even in noisy spectra. Furthermore, we are effectively doing a blind search for PAH molecules since all frequency spacings within our bandwidth are searched. In this talk, I will describe this novel technique and present the current status of this project, as we have recently obtained GBT observations of the IC 348 star-forming region in the Perseus molecular cloud.



**Chris Hales**

**CHILES Con Pol: Probing galaxy evolution, the dark Universe, and cosmic magnetism with a deep 1000 hour Jansky VLA survey**

I will describe a 1000 hour campaign to observe 0.2 square degrees of the COSMOS field in full polarization continuum at 1.4 GHz with the Jansky VLA, as part of a joint program with the spectral line COSMOS HI Large Extragalactic Survey (CHILES). When complete, this CHILES Continuum Polarization (CHILES Con Pol) survey is expected reach an unprecedented SKA-era sensitivity of 0.7  $\mu$ Jy per 4" FWHM beam. In this talk I will present the key goals of CHILES Con Pol, which are to probe galaxy evolution using source counts, dark energy using weak lensing, and the unknown origin of cosmic magnetism using Faraday rotation measure analysis.

**Huib Intema**

**The making of T-RaMiSu**

The intrinsic large field-of-view of low-frequency radio interferometers is both a pain and a pleasure. With the right data reduction tools in hand, observing with the VLA or GMRT at frequencies below 0.5 GHz provides the user with instantaneous large sky coverage - even single pointings cover at least several square degrees. For pointed observations of a few hours, there are typically a few hundred detectable sources, that all have to be imaged and deconvolved to reach the anticipated sensitivity. In this talk I will describe the T-RaMiSu project, a deep, high-resolution radio mini survey with the GMRT at 150 MHz, covering more than 65 square degrees of sky with just 14 pointings.

**Brian Lacki**

## **Radio Diagnostics of the Inhomogeneous Intergalactic Medium**

A new class of mysterious radio bursts, only a few milliseconds long and very bright ( $> \sim \text{Jy}$ ), has been discovered. The bursts appear to be coming from outside the Galaxy. The diffuse plasma of the intergalactic medium disperses these bursts. By measuring the delay at different frequencies, one can calculate the dispersion measure (DM), and with it, the integrated column density along the line of sight and the distance in the IGM. But the IGM is inhomogeneous; how does this affect the measurement? I describe my attempts to find out by realizing simulated lines of sight through the IGM using the lognormal approach. I determine the probability distribution of DMs at a given  $z$  and redshifts at a given DM. With these probability distributions, I set error bars on the redshifts of the fast radio bursts; for the Lorimer Burst, the redshift is uncertain at the factor of 2 level with 95% confidence. I will also describe my explorations into whether the free-free absorption of the IGM is visible.

**Walter Max-Moerbeck**

**The radio universe as seen from Socorro**

During my first year at NRAO I was involved in a number of exciting projects that I will briefly review in this talk. The first one is concerned with the study of quasi-periodic oscillations (QPOs) in AGNs. QPOs have been well-studied in X-ray binaries but the situation in AGNs is less clear. I will describe the case of J1359+4011, in which a QPO with a period 120-150 days has been persistently detected in 5 years of 15 GHz observations from the Owens Valley Radio Observatory blazar monitoring program. Multifrequency VLBA observations can guide the search for the mechanism responsible for this peculiar behavior. The second project is an exploration of fast time variability in extragalactic radio sources, aimed at determining dispersion measures with steady sources of radiation as background emitters. By using the latest capabilities of the VLA and the GBT we plan to contribute to the resolution of the controversy this new technique generated in the literature. The third project makes use of the high spatial resolution of the VLBA to make precise measurements of positions for spacecraft navigation. I will describe current efforts to obtain near-real time correlation with the VLBA, and the results of recent tests of this new capability that has a lot of potential for spacecraft navigation.

**Andrew Baker**

## **Dusty Star-Forming Galaxies at High Redshift**

Since the discovery of submillimeter galaxies in the late 1990s, we have come to appreciate that a complete picture of galaxy evolution must include the overlapping populations of obscured, dusty star-forming galaxies (DSFGs) that are much more prevalent at high redshift than in the local universe. Gains in our understanding of DSFGs have followed the deployment of new instruments that probe expanded ranges in wavelength, redshift, and/or observational efficiency, a trend that will surely continue as the Atacama Large Millimeter/submillimeter Array (ALMA) moves closer to full operations. I will discuss recent results on the redshift distributions, evolutionary states, and detailed internal properties of DSFGs, along with what we can learn from lensed DSFGs about intervening mass distributions. I will also provide a personal perspective on where ALMA might be able to make the most significant contributions over the next few years.

**Amanda Heiderman**

**Bridging the Gap: Connecting Galactic and Extragalactic Studies of Star Formation**

Star formation is a key physical process for the origin of stars and planets as well as the formation and evolution of galaxies. Observational studies of how stars form in the Universe have evolved into two separate fields: Galactic and extragalactic star formation. Galactic studies focus on detailed studies of individual star forming regions on  $\sim$ pc size scales in the Milky Way, while extragalactic studies typically focus on galaxy-wide scales or  $\sim$ kpc size regions. I will discuss efforts to connect Galactic and extragalactic studies of star formation. I will also introduce the VIRUS-P Investigation of the eXtreme ENvironments of Starbursts (VIXENS) Survey of 15 nearby interacting/starburst galaxies. I will highlight first results from VIXENS and discuss the relation between star formation and gas content in a nearby galaxy merger on spatially resolved  $\sim$ kpc scales.

**Amanda Kepley**

## **The GBT: A Mapping Machine for Dense, Star-Forming Gas in Nearby Galaxies**

In both the Milky Way and nearby galaxies, the presence of dense molecular gas is correlated with recent star formation, suggesting that the formation of this gas may represent a key regulating step in the star formation process. Testing this idea requires wide-area, high-resolution maps of dense molecular gas in galaxies to explore how local physical conditions drive dense gas formation. Until now, these observations have been limited by the faintness of dense gas tracers like HCN and HCO<sup>+</sup>, but the sensitivity of new instruments like the Robert C. Byrd Green Bank Telescope (GBT) - the largest single-dish, millimeter telescope - are poised to change this picture. We present GBT maps of the dense gas tracers HCN and HCO<sup>+</sup> in the prototypical nearby starburst galaxy M82. The HCN and HCO<sup>+</sup> in the disk of M82 correlates both with recent star formation and the diffuse molecular gas and shows kinematics consistent with a rotating torus. HCO<sup>+</sup> emission is also associated with the outflow of molecular gas previously identified in CO. These observations mark the first time that dense molecular gas like HCO<sup>+</sup> has been associated with an outflow in a nearby galaxy and suggests that the outflow of dense molecular gas from the center of galaxies like M82 may regulate the star formation globally. Finally, the CO-to-HCN and CO-to-HCO<sup>+</sup> line ratios reveal that there is more dense gas at the center of M82, pointing to the starburst as a key driver of this relationship. These results establish that the GBT can efficiently map the dense molecular gas at 90 GHz in nearby galaxies; this capability will increase further with the 16-element feed array currently being built for the GBT.

**Sabrina Stierwalt**

## **Star Formation in Dwarf-Dwarf Mergers: Fueling Hierarchical Assembly**

We present early results from the first systematic study a sample of isolated interacting dwarf pairs and the mechanisms governing their star formation. Low mass dwarf galaxies are ubiquitous in the local universe, yet the efficiency of gas removal and the enhancement of star formation in dwarfs via pre-processing (i.e. dwarf-dwarf interactions occurring before the accretion by a massive host) are currently unconstrained. Studies of Local Group dwarfs credit stochastic internal processes for their complicated star formation histories, but a few intriguing examples suggest interactions among dwarfs may produce enhanced star formation. We investigate star formation rates, global galaxy colors, and gas fractions as a function of dwarf pair separation (i.e. the dwarf merger sequence) and dwarf-dwarf mass ratio to determine whether dwarf-dwarf interactions alone are enough to trigger significant star formation. This project is a precursor to an ongoing effort to obtain high spatial resolution HI imaging to assess the importance of sequential triggering caused by dwarf-dwarf interactions and the subsequent affect on the more massive hosts that later accrete the low mass systems.



**Jennifer Donovan Meyer**

**Finding tiny, gas-rich galaxies on the edge of the Local Group**

I will present ultraviolet (UV) follow-up of a sample of potential dwarf galaxy candidates selected for their neutral hydrogen (HI) properties. As a result of the low UV background seen by the GALEX satellite and its large and publicly available imaging footprint, we are able to identify potential new, low mass galaxies from published GALFA-HI and ALFALFA survey cloud catalogs. We also identify the UV counterparts to a sample of known dwarf galaxies observed by GALFA-HI, which when combined with the published ALFALFA dwarf catalog (Huang et al. 2012), yields a comprehensive picture of the nearby dwarf galaxy population in the UV. These results indicate that finding dwarf galaxies by first searching for their neutral gas component is a viable method to locate these optically faint systems, especially at distances of  $\sim 1$  Mpc from the Milky Way.

**Amy Reines**

## **Revealing Massive Black Holes in Dwarf Galaxies with the VLA and Chandra**

Supermassive black holes (BHs) live at the heart of essentially all massive galaxies, power AGN, and are thought to be important agents in the evolution of their hosts. However, the origin of these monster BHs is largely unknown. While direct observations of the first "seeds" of supermassive BHs in the infant Universe are unobtainable with current telescopes, finding and studying dwarf galaxies hosting massive BHs today can provide valuable constraints on the masses, host galaxies, and formation mechanism of supermassive BH seeds. We have recently completed the first systematic search for AGN in dwarf galaxies using optical spectroscopy, increasing the number of known dwarfs with massive BHs by more than an order of magnitude (Reines et al. 2013). However, this optical search is biased towards BHs radiating at high fractions of their Eddington limit in galaxies with little on-going star formation. Alternative search techniques and diagnostics at other wavelengths are necessary to make further progress. I will discuss our efforts to find and study massive BHs in dwarf galaxies using observations with the VLA and Chandra. These radio and X-ray observations are more sensitive to weakly accreting massive BHs and are already beginning to reveal massive BHs hidden at optical wavelengths in star-forming dwarf galaxies.

**Sui Ann Mao**

**Viewing galaxies in Faraday depth space**

Improvements in the frequency coverage and spectral resolution of current radio telescopes allow one to construct high fidelity Faraday depth cubes from polarization observations of external galaxies. Unfortunately, interpreting these Faraday depth cubes is not straightforward. In this talk, I will discuss various challenges we face when attempting to extract properties of the underlying magneto-ionic medium in the target galaxy from their Faraday depth cubes. I will also outline how constructing simple models of the galaxy can help us unpack information from wide-band polarization data.

**Drew Brisbin**

## **Extended [CII] and [OI] emission from star forming galaxies at $z \sim 1.8$**

We have recently detected the [CII] 158 micron line in eight star forming galaxies at redshifts 1 to 2 using the redshift(z) Early Universe Spectrometer (ZEUS) and augmented this survey with observations of the [OI] 63 micron line and far infrared photometry from the PACS and SPIRE Herschel instruments as well as Spitzer IRS spectra from the literature showing PAH features. Our sources exhibit above average gas heating efficiency, many with [CII]/FIR > 0.01. The relatively strong [CII] emission indicates our sources are dominated by star formation powered PDRs, extending to kpc scales. In addition to the exceptionally efficient PDR powered [CII] emission, we suggest that the [CII]/FIR and [CII]/PAH ratios indicate additional sources of [CII] emission possibly including shock powered microturbulence.

**Jacqueline Hodge**

## **Resolved Studies of High-Redshift Submillimeter Galaxies**

Submillimeter galaxies (SMGs) are dusty, gas-rich galaxies undergoing some of the most intense bursts of star formation in the known universe. As the likely progenitors of today's massive elliptical galaxies, they are key players in models of galaxy formation and evolution. Yet despite this fact, there is still much we do not understand about their nature and role in hierarchical galaxy formation. I will present Karl G. Jansky Very Large Array (VLA) and Atacama Large Millimeter Array (ALMA) observations of the gas and dust in submillimeter galaxies. The VLA observations allow us to image the molecular gas on scales of  $\sim 1$  kpc just 1.5 Gyr after the big bang, giving an unprecedented view of the material which feeds the star formation. The state-of-the-art ALMA observations allow us to identify counterparts to these dust-obscured giants. Together, these facilities shed light on the physical processes involved in fueling the massive starbursts and, ultimately, help us place SMGs in the cosmological context.

