The Interstellar Medium in High Redshift Galaxies Comes of Age

Oral Presentation Abstracts
Friday - Sept 14, 2012

Desika Narayanan (University of Arizona)

Physical Properties of the Star-forming ISM in Galaxies Near and Far

I review the current status of models for the molecular ISM in galaxies. In particular, I will focus on galaxy-wide star formation efficiencies, the Kennicutt-Schmidt Star Formation Law and the CO-H_2 conversion factor in galaxies.

Neal Evans (University of Texas at Austin)

Connections Between the Milky Way and High-z Galaxies

Star formation in dense regions of Milky Way molecular clouds has some resemblance to star formation in high-z starbursts. I will review the evidence for this and discuss some studies within the Milky Way and in high-z galaxies that could test this picture and deepen our understanding of what controls star formation rates.

Raquel Monje (Caltech)

Darek Lis (Caltech)
David Neufeld (Johns Hopkins University)
Thomas Phillips (Caltech)

Hydride Molecules in the Interstellar Medium of the Nearby and High Redshift Universe

Studying the astrochemistry of the early Universe is crucial for understanding the properties of molecular gas in galaxy formation and for providing fundamental constraints on galaxy evolution. To date, a fairly small number of species, other than CO, have been detected at z $>$ 2 (e.g. HCN, HNC, CN, H_2O, HCO^+) and used as tracers of molecular gas. Recent observations with the Herschel Space Observatory (HSO) have shown strong spectroscopic signatures from light hydrides such as water (H_2O) and hydrogen fluoride (HF) within the Milky Way and in nearby active galaxies. The remarkable Herschel/HIFI results suggest, that the HF $J = 1 - 0$ transition promises to yield an extremely sensitive probe of the diffuse molecular gas along the line-of-sight to background far-infrared continuum sources and, as predicted earlier by chemical models, a valuable surrogate for molecular hydrogen in the nearby and high redshift universe. Water on the other hand, a main reservoir of oxygen, and an important coolant of dense gas, plays an essential role in the physics and chemistry of the dense interstellar medium (ISM) being strongly depleted on dust grains in cold gas, but abundant in warm regions influenced by energetic processes associated with star formation.

Following-up on the Herschel discovery on molecular hydrides within the ISM of the Milky Way galaxy, we are conducting a search for the fundamental rotation line of HF towards nearby galaxies with a Herschel/HIFI OT2 program and of both HF and H_2O, towards strongly lensed high-redshifted galaxies with bright submillimeter continuum using ground-based facilities, such as, the Caltech Submillimeter Observatory (CSO). Results and interpretation from these observations and future prospects will be presented at the meeting.

Ran Wang (NRAO/Steward Observatory)

Chris Carilli (NRAO)
Xiaohui Fan (Steward Observatory)
Fabian Walter (MPIfA)
Dominik Riechers (Caltech)

Observational Clues to the Epoch of Reionization

Understanding the formation of the first supermassive black holes (SMBHs) and galaxies is one of the primary goals of modern galaxy evolution studies. Large samples of quasars and star forming galaxies have been discovered at z$\sim$6 and higher during the last decade. The detections of FIR-emitting dust, molecular CO, and fine structure line emission in the host galaxies of quasars at z$\sim$6 present the first evidence of massive star formation and SMBH-galaxy coevolution close to the end of cosmic reionization. The large submillimeter/millimeter and radio telescopes, such as the JVLA and ALMA, now present a unique opportunity to study the dust and gas components and star formation in these earliest SMBH-galaxy systems in details. In this presentation, I will review recent submillimeter, millimeter, and radio observations of the most distant quasar host galaxies. These observations directly measure the FIR luminosity, dust mass, physical and dynamical properties of the molecular and cool atomic gas components and set key constraints on the star formation rate/surface density and SMBH-bulge relationships at the earliest epoch.

Nick Scoville (Caltech)

Measuring the ISM in High-z Galaxies

I will discuss different techniques for evaluating the ISM content of high redshift galaxies and develop the basis for using the long wavelength dust continuum as a mass tracer – which is must faster and less fraught with analysis difficulties than the commonly used CO lines. This technique is enabled by ALMA and I will present preliminary results from an ALMA Cycle0 project.

Simona Gallerani (Suola Normale Superiore di Pisa)

Roberto Maiolino (University of Cambridge)
Roberto Neri (IRAM)
Tohru Nagao (Kyoto University)
Sergio Martin (ESO)
Carlos De Breuck (ESO)

Observations of Far Infrared Emission Lines at z∼4

The detection of far infrared emission lines at high redshift has opened a new avenue to discover primordial galaxies and to characterize the interstellar medium in the early Universe. I will present observations of several far infrared emission lines (i.e. [CII] 158 micron; [NII] 205 micron; CO(5-4)) detected in a lensed quasar at z=4.4 with the Plateu de Bure Interferometer. I will show how these observations allow us to measure several properties of the host galaxy, namely the density of the molecular clouds, the molecular hydrogen and the dynamical mass, the gas metallicity, and the radiation field intensity. Moreover, I will show the detection of the most powerful quasar-driven outflow ever discovered, revealed through prominent, broad wings of the [CII] 158 micron emission line in a quasar at z=6.4.

Alberto Bolatto (University of Maryland)

Dust and Metallicity

Dust plays a central role at determining the chemistry and thermodynamics of the interstellar medium in galaxies. Indeed, the main processes responsible for heating the neutral and the molecular medium and for forming H_2 rely on dust. Nevertheless, simple relations such as that between dust-to-gas mass ratio and heavy-element abundance (metallicity) in galaxies remain poorly characterized and understood. The dominant dust formation mechanisms are also not uniformly agreed on. Understanding dust and metallicity is particularly interesting at high redshifts, where millimeter-wave observations are starting to push both into the regime of "normal" galaxies with lower metallicities, and to redshifts so high that some dust production mechanisms cannot have time to act on the ISM.

Joaquin Vieira (Caltech)

John Carlstrom (University of Chicago)
Dan Marrone (University of Arizona)
Axel Weiss (MPIfR)
Yashar Hezaveh (McGill University)
Scott Chapman (Cambridge University)

ALMA Unveils High Redshift Cosmic Microscopes Discovered by the South Pole Telescope

The South Pole Telescope has systematically identified large numbers of high-redshift strongly gravitationally lensed systems. These sources are selected by their extreme mm flux, which is largely independent of redshift and lensing configuration. I will report results from the first blind redshift survey undertaken with the recently commissioned Atacama Large Millimeter Array (ALMA). We targeted 26 extraordinarily bright and dusty sources selected from a 2500 deg^2 mm survey conducted by the SPT and obtained redshifts via molecular carbon monoxide (CO) lines. We determine that roughly 40% of these sources lie at $z > 4$, indicating that we have uncovered the missing high-redshift tail of starburst galaxies. Two sources are at $z > 5.6$, placing them among the highest redshift starbursts known, and indicating that large reservoirs of dust can be present in massive galaxies at the end of the epoch of cosmic reionization. These sources were additionally targeted with high resolution imaging with ALMA, unambiguously demonstrating them to be strong gravitationally lensed by foreground structure. We are undertaking a comprehensive and systematic followup campaign to use these "cosmic magnifying glasses" to study the infrared background in unprecedented detail, conduct detailed investigations of the properties of massive galaxies at $z \sim 1$, inform the condition of the interstellar medium in starburst galaxies at high redshift, and place limits on dark matter substructure. I will discuss the scientific context and potential for these strongly lensed starburst galaxies, give an overview of our team's extensive followup efforts, and describe our preliminary science results.

Johannes Staguhn (Johns Hopkins University/Goddard Space Flight Center)

Attila Kovacs (Caltech)
Fabian Walter (MPIA Heidelberg)
Roberto Decarli (MPIA Heidelberg)
Alexander Karim (Durham University)
Eva Schinnerer (MPIA Heidelberg)

GISMO Surveys of the High-Redshift Universe

We will present an update on our 2 mm surveys of the GISMO Deep Field in GOODS-N and in the COSMO survey in the COSMOS field.

Ray Norris (CSIRO Astronomy Space Science)

ULIRG F00183 - Watching the Birth of a Quasar

We have found a compact (VLBI) radio-loud AGN with jets in the center of the extreme ULIRG F00183-7111, representing an extreme example of the class of radio-loud AGNs buried within dusty star-forming galaxies. This source appears to be a rare example of a ULIRG glimpsed in the (presumably) brief period as, the jets start to emerge from the AGN while the host galaxy is still undergoing its post-merger starburst. We have detected CO from this galaxy with the ATCA, have proposed ALMA observations, and also have a program of optical and infrared observations so we can dissect this brief but important phase in the early evolution of galaxies.

Tommy Wiklind (ESO/JAO)

The Highest Redshift Submm Galaxy

We present the discovery of a submillimeter galaxy potentially at a redshift z∼6 in the GOODS South field. The galaxy was first detected with the LABOCA instrument on the APEX telescope. Its nature and association with a distant galaxy was determined through high angular resolution observations with the SubMillimeter Array (SMA) telescope. The submillimeter emission appears to be associated with a high redshift galaxy. The high-z galaxy is observed with HST/ACS, VLT/ISAAC, Spitzer/IRAC and MIPS instruments as well as Herschel PACS/SPIRE. Emission from the galaxy is, however, only detected at IRAC and longer wavelengths, suggesting a very high redshift or extreme extinction in a lower redshift object. While the photometric data strongly suggests a very high redshift, the final determination of the nature of this object can only be achieved through line observations in the mm/submm.

Pierre Cox (IRAM)

The Study of Molecular and Atomic Gas in High-z Galaxies and Quasars: An Historical Overview

The study of the interstellar medium, more specifically of the molecular gas, in galaxies and quasars at high redshifts using sub/millimeter facilities started in the early 1990's with the detection of CO emission in a z-2.3 galaxy by Bob Brown and Paul Vanden Bout.

With the advances in technology and the increasing sensitivity of facilities worldwide, this field of research has steadily grown and is today central in our understanding of the physical and chemical conditions in star-forming galaxies in the early universe.

This review will present the historical development of the field emphasizing the role played by the major facilities involved in the 1990's, describe some of the difficulties encountered and summarize the main achievements.

Recent studies will then be described, illustrating high angular resolution observations and successes in detecting species other than CO.

Finally, the review will conclude by showing how ALMA, NOEMA and the Jansky VLA will impact the study of the interstellar medium in high-z galaxies and quasars.

Oral Presentation Abstracts
Saturday - Sept 15, 2012

Claudia Lagos (Durham University)

Simulations and Modeling of the ISM in Galaxies

The latest observations of the carbon monoxide and atomic hydrogen contents of local and high-redshift galaxies, coupled with how these correlate with star formation activity, have revolutionized our ideas about how to model star formation in a galactic context. A successful theory of galaxy formation has to explain some key facts: i) high-redshift galaxies have higher molecular gas fractions and star formation rates than local galaxies, ii) scaling relations show that the atomic-to-stellar mass ratio decreases with stellar mass in the local Universe, and iii) the global abundance of atomic hydrogen evolves very weakly with time. I will review how modern cosmological simulations of galaxy formation attempt to put together these pieces and highlight how "parallel" approaches, which simultaneously solve dark matter and gas physics, and "serial" approaches, which first solve the dark matter N-body problem and then deal with gas physics using semi-analytic models, differ and complement each other. I will review the observable predictions, what we think we have learned so far and what still needs to be done in the simulations to allow robust testing by the new observations expected from e.g. ALMA, PdBI, MeerKAT, SKA.

Jacqueline van Gorkom (Columbia University)

Ximena Fernandez (Columbia University)
Kelley Hess (University of Capetown)
Emmanuel Momjian (NRAO)
DJ Pisano (University of West Virginia)
Tom Oosterloo (ASTRON)

CHILES a pilot for an EVLA HI Deep Field

Although the interstellar medium in high redshift galaxies is coming of age, little is known about the most abundant element, neutral atomic hydrogen beyond a redshift of 0.08. The recent upgrade of the Very Large Array will help to correct that situation. It will soon be possible to observe in one setting all the HI in a cone from z=0 to z=0.45. I will present the preliminary results of a pilot for such a survey,the COSMOS HI Large Extragalactic Survey, where we have observed one pointing in the COSMOS field from z=0 to z=0.18.

Additional authors:

Kathryn Kreckel, Attila Popping, Trish Henning, Marc Verheijen, Laura Chomiuk, Eric Wilcots, Matt Bershady, David Schiminovich. Nick Scoville, Rien van de Weygaert, Joe Lazio, Aeree Chung

Kartik Sheth (NRAO)

Kim Scott (NRAO)
Vernesa Smolcic (ESO)
Manuel Aravena (ESO)
Nick Scoville (Caltech)
Paul Vanden Bout (NRAO)

A Beautiful SMG Pair in COSMOS

We present preliminary results of the molecular gas emission in a pair of submillimeter galaxies in the COSMOS field at z$\sim$1.5, separated by $\sim$80 Mpc. The galaxies are luminous ULIRGs and are well-detected at all bands from the optical through the radio. However, the radio-bright galaxy has significantly weaker CO emission than its neighbor suggesting differing AGN activity at their cores. We discuss these differences along with the galactic structure, mass and star formation activity in this pair. This pair also highlights the revolution expected in our understanding of galaxy number counts and luminosity functions from higher resolution interferometric observations with the new generation of telescopes such as ALMA and VLA.

Dominik Riechers (Cornell University)

Physical Conditions in the Interstellar Medium of High-Redshift Galaxies Mass Budget and Gas Excitation

Following the first pioneering efforts in the 1990s that have focused on the detection of the molecular interstellar medium in high redshift galaxies, the past years have brought great advances in our understanding of the actual physical properties of the gas, which set the conditions for star formation. Observations of the ground-state CO $J = 1-0$ line have furnished crucial information on the total masses of the gas reservoirs, as well as reliable dynamical mass and size estimates. Detailed studies of rotational ladders of CO have provided insight on the temperature and density of the gas. Investigations of the very dense gas associated with actively star-forming regions in the interstellar medium, most prominently through HCN and HCO^+, have enabled a better understanding of the nature of the extreme starbursts found in many high-redshift galaxies, which exceed the star formation rates of their most active present-day counterparts by an order of magnitude. Studies of far-infrared atomic fine structure lines, in particular [CII], have given key information on the radiation fields pervading the star-forming gas, and thus, on the mechanisms giving rise to the observed excitation of the gas. Key progress in this area has been made through targeted studies of few, well-selected systems with current facilities. The completion of the Karl G. Jansky Very Large Array and the Atacama Large (sub)Millimeter Array in the near future will provide the means to generalize these findings to the general high redshift population based on unbiased studies of "normal" star-forming galaxies back to the earliest cosmic epochs.

Chelsea Sharon (Rutgers - The State University of New Jersey)

A. J. Baker (Rutgers - The State University of New Jersey)
A. I. Harris (University of Maryland)
D. Lutz (Max-Planck-Institut fur extraterrestrische Physik)
L. J. Tacconi (Max-Planck-Institut fur extraterrestrische Physik)
A. S. Tagore (Rutgers-The State University of New Jersey)

Spatial Variation of CO Excitation in High-z Galaxies

Previous studies of the molecular gas excitation in high-redshift galaxies have focused on galaxy-wide averages of CO line ratios. However, it is possible that these averages hide spatial variation on sub-galactic scales, disguising the true distribution and conditions of the molecular gas within star-forming galaxies. Even in the pre-ALMA era we have begun to see evidence for spatial variation of CO excitation in star-forming galaxies at $z > 2$, aided both by the increased frequency coverage of the Jansky Very Large Array (allowing high resolution observations of the CO($J = 1 - 0$) line, the best tracer for the coldest molecular gas) and by the benefits of gravitational lensing for spatially extended sources. I will show new results for rest-UV selected and submillimeter selected systems that reveal spatial and/or spectral variations in CO excitation, thereby illustrating the value of high resolution mapping in order to fully characterize the molecular ISM in high-redshift galaxies.

Minnie Mao (NRAO)

Bjorn Emonts (CSIRO)
Ray Norris (CSIRO)

Molecular CO 1-0 in High Redshift Radio Galaxies Using the ATCA

In 2009, the Compact Array Broadband Backend (CABB) was installed on the Australia Telescope Compact Array (ATCA). CABB offers $2 \times 2\,\mathrm{GHz}$ instantaneous bandwidth making it an ideal instrument to detect and spatially resolve high-redshift molecular gas.

Our team has observed a complete sample of high-redshift radio galaxies using CABB with the intention of detecting CO(1-0) (Emonts et al. 2011). In this talk I will summarize ATCA's upgraded spectral line capabilities and present and discuss our work on molecular gas in high-redshift radio galaxies, including the detection of CO(1-0) in two $z \sim 2$ radio galaxy.

Mark Sargent (CEA Saclay Service d'Astrophysique)

Emanuele Daddi (CEA Saclay Service d'Astrophysique)
Matthieu Bthermin (CEA Saclay Service d'Astrophysique)
Georgios Magdis (University of Oxford)
Fabian Walter (MPIA Heidelberg)
David Elbaz (CEA Saclay Service d'Astrophysique)

Star Formation and Molecular Gas over Cosmic Time

The observations of the past several years revealed the existence of a so-called 'main sequence' for star-forming galaxies out to high redshift. While the majority of star-forming galaxies obeys this fairly tight relation between star-formation rate and stellar mass, a smaller subset of the population – referred to as 'starbursts' – displays specific star-formation rates and star-formation efficiencies that can exceed those of normal (main-sequence) galaxies by an order of magnitude. The current interpretation of the CO-line emission from the roughly three dozen normal star-forming galaxies detected to date at $z > 0$ suggests that there is a high degree of homogeneity between low- and high-redshift main-sequence galaxies in terms of their molecular gas properties. I will discuss how we can exploit this fact to already now infer the molecular gas content of the far larger samples of distant star-forming galaxies that await detection with ALMA and the upgraded VLA.

Manuel Aravena (ESO)

Chris Carilli (NRAO)
Fabian Walter (MPIA)
Dominik Riechers (Cornell University)
Jaqueline Hodge (MPIA)
Emanuele Daddi (CEA Saclay)

Unveiling the CO Properties of Star-forming Disk Galaxies at z∼1.5 with the VLA

The population of galaxies that dominates the peak of cosmic star formation is composed by a mix of star forming disk and interacting galaxies with typical star formation rated (SFRs) of ~ 100 $M_\odot$ yr^{-1}. A major step to characterize the properties of these galaxies has been the recent detection of substantial reservoirs of molecular gas in disk galaxies at $z \sim 1.5$. The derived gas masses in these cases are comparable to that observed in hyper-luminous starburst and quasar host galaxies, but in galaxies forming stars at $10\times$ lower rates. In this presentation, I will discuss the relevance of CO observations in these galaxies, and summarize our current efforts to characterize their cold molecular gas using the Karl Jansky Very Large Array (VLA). Finally, I will show recent results on a deep blind VLA search for CO emission from star-forming galaxies in a galaxy overdensity at $z \sim 1.5$.

Andrew Harris (University of Maryland)

Andrew Baker (Rutgers University)
David Frayer (NRAO)
Ian Smail (University of Durham)
Galen Watts (NRAO)
H-ATLAS Consortium (Everywhere)

GBT Zpectrometer CO $J = 1 - 0$ Observations of Massive Dusty Star Forming Galaxies at z=2 to 3.5

In their 1995 memo, Frayer and Vanden Bout made a strong case for GBT observations of the redshifted CO $J = 1-0$ line, extrapolating from the two high-z galaxies with molecular emission and theoretical models of galaxy evolution (GBT memo 137). Twelve years later routine observations of CO $1 - 0$ from $z = 2 - 3.5$ galaxies started with the Zpectrometer, an ultrawideband spectrometer specifically designed for the deep integrations needed for routine observations and line searches.

Here we review Zpectrometer CO $1-0$ observations of high-redshift galaxies with the GBT. For galaxies with millimeter-wave detections, comparison of $J = 1 - 0$ to higher-J line fluxes reveals the presence of extended low-excitation material that increases gas mass estimates above those from previous millimeter-wave fluxes alone. Spectroscopic CO detections of 11 targets selected from the Herschel-ATLAS survey confirms the existence of massive gas reservoirs within those DSFGs. The CO redshift distribution of these 350 micron-selected galaxies is strikingly similar to the optical redshifts of 850 micron-selected submillimeter galaxies (SMGs) over the same redshift range, clarifying our understanding of when massive spheroids form. Many of the bright H-ATLAS galaxies are expected to be amplified by foreground gravitational lenses. Analysis of CO linewidths and luminosities provides a method for finding approximate gravitational lens magnifications from spectroscopic data alone, yielding amplifications of ~ 3 to ~ 20. Correcting for magnification allows more precise estimates of gas masses, which range to $M_{\rm gas} > 10^{11}\ M_{\odot}$. Most galaxy luminosities are consistent with an ultra-luminous infrared galaxy (ULIRG) classification, but three are candidate hyper-LIRGs with luminosities greater than $10^{13}\ L_{\odot}$.

Karl Menten (MPI für Radioastronomie)

Constraints on Variations of Fundamental Constants from High Redshift Atomic and Molecular Emission and Absorption

The standard model of physics does not require the fundamental constants of nature (FCs) to be constant in space and time. In the past, quests to measure possible variations have mostly been performed with atomic and also molecular hydrogen absorption lines at (observer frame) optical wavelenths. At (sub)millimeter and radio wavelengths, in various cases dramatically different dependences of certain spectral lines on FCs allow for extremely sensitive constancy tests. At present, only five (sub)mm-wavelength and/or absorbers are known at cosmological distances, all at z ¡ 0.9 and thus probing lookback times up to about 7 Gyr. Further back in time, to 11.3 Gyr, applies our recent sensitive limit on a combination of the fine structure constant and the proton-to-electron mass ratio that we determined from sensitive measurements of emission from an excited rotational CO line and a fine structure line from atomic carbon toward a high redshift (z = 2.79) quasar host galaxy. We shall report on the latter, summarize some recent results from gravitational lens absorbers and give an outlook on opportunities with the ALMA and the VLA.

Fabian Walter (MPIA)

Chris Carilli (NRAO)

Molecular Deep Fields

Recent progress in cosmological deep fields studies has been impressive, but current knowledge of the formation of galaxies in the universe is based almost exclusively on blank optical and near-IR deep field surveys of the stars, star formation, and ionized gas. Observations of the molecular gas mass, which as the fuel for star formation is the fundamental basis of the cosmic star formation history, have been limited to follow-up studies of galaxies that have been pre-selected from optical/NIR deep surveys.I will discuss future prospects of blind CO surveys that are now becoming feasible with ALMA and present some first results of a first CO deep field of the Hubble Deep Field obtained with the IRAM PdBI that resulted in a number of blind CO detections, including the elusive galaxy HDF850.1.

Min Yun (University of Massachusetts)

High-z ISM Future Perspectives

Since the first detection of CO from the z=2.3 galaxy IRAS F10214+4724 by Brown & Vanden Bout in 1991, our understanding of ISM in high redshift galaxies have grown steadily but slowly. This is a field traditionally limited by the sensitivity of available instruments, but this is about to change significantly by new instruments and facilities such as the ALMA, LMT, and CCAT. I will briefly review how understanding the cold gas content of high redshift galaxies may yield unique insights into the mass build-up history of galaxies. I will also review a broad suite of future instruments and facilities that will enable such a study.

Poster Presentation Abstracts

Andrew Baker (Rutgers University)

Amitpal S. Tagore (Rutgers University)
Dieter Lutz (MPE Garching)
Linda J. Tacconi (MPE Garching)
Sahar S. Allam (FNAL)
Huan Lin (FNAL)

Molecular Gas in Lensed Lyman Break Galaxies

In the Solomon & Vanden Bout (2005) review of "Molecular Gas at High Redshift," the important population of rest-UV-selected Lyman break galaxies (LBGs) is represented by a single lonely point for the lensed arc MS1512-cB58. Seven years later, now larger samples of lensed LBGs can provide valuable insights into the population's range of evolutionary states. I will present CO(3-2) detections of a small sample of $z \geq 2$ lensed systems, carefully culled from the Sloan Digital Sky Survey, and show how they and similar results from the literature test the applicability of the Schmidt-Kennicutt relation at high redshift and constrain models of galaxy evolution.

Jake Borish (University of Virginia)

Vivian U (UC Riverside)
Aaron Evans (UVA)
Andre Wong (UVA)
George Privon (UVA)
Dong-Chan Kim (NRAO)

Warm H_2 Emission in Interacting Disk Galaxies

Optical imaging of Luminous Infrared Galaxies (LIRGs; $L_{IR} > 10^{11}$ L_{sun}) typically reveals interacting or merging pairs of disk galaxies with tidally distorted gas disks. Furthermore, HST imaging has shown that many LIRGs with $L_{IR} > 10^{11.4}$ L_{sun} contain an abundance of luminous super star clusters (SSCs); these regions of intense star formation are thought to be triggered by the interaction. We have obtained narrow band imaging of the 2.122 μm warm H_2 line from 4 LIRGs. We determine whether the warm H_2 emission is compact and associated with bright star formation regions or AGN where present, or if it is extended and coincident with extended tidal features and thus possibly associated with wide-scale shocks.

Sean Cutchin (NRL)

Namir Kassim (NRL)
Brian Hicks (NRL)
Joseph Lazio (JPL/Caltech)
Rick Perley (NRAO)
Frazer Owen (NRAO)

Continuously Observing the High-z Universe with a VLA Low Band Commensal (LBC) System

The ability to observe with more than one beam simultaneously is a powerful multiplier of a telescope's function. Traditional radio telescopes (eg. the GMRT, WSRT and VLA) have feed systems which offer observers the ability to make simultaneous observations at multiple frequencies, providing multi-wavelength information on the target fields. An amplification of this ability is being explored for the modernized Jansky VLA (hereafter VLA): namely a system to seamlessly observe with the new Low Band prime focus broadband receiver during normal cassegrain observations. This proposed commensal system would piggyback essentially all of the VLA's normal observing time to make observations in the frequency range of $\sim 60 - 480$ MHz. Shared fields with other multibeaming, dipole based arrays that share the same sky with the VLA, e.g. the Long Wavelength Array (LWA), would be straightforward.

The resulting wide-field, low frequency images can be used to buildup a database of source information in this frequency range, and to search for exotica such as transients. Additionally, the VLA Low Band Commensal system (LBC) capability has potentially interesting applications for study of the interstellar medium in high-z galaxies.

The observations will be made in spectral line mode, enabling blind and targeted searches for OH Megamasers (OHMs). OHMs are produced in major galaxy mergers undergoing extreme star formation, and can thus be used as probes of their environments. The VLA LBC system has a 100 MHz band centered on 330 MHz, thereby effecting a search for OHMs at redshifts $3.4 \lesssim z \lesssim 5.0$. Here we describe how the VLA LBC system might be implemented, and explore early ideas for its use in the study of the interstellar medium of galaxies at high redshifts.

Carol Lonsdale (NRAO)

Mark Lacy (NRAO)
Amy Kimball (NRAO)
Colin Lonsdale ()
Jim Condon (NRAO)

Unveiling the Most Luminous Dust-Enshrouded Quasars Results from ALMA, VLA and WISE

We seek to investigate the sequence of events, starting with the collision and merging of massive galaxies, followed by starburst activity, ignition of AGN activity fueled by black hole accretion, and ending in formation of a giant elliptical galaxy. In particular, the relationship between the starburst and the AGN, and the role of radio-mode feedback (radio jets from the AGN disrupting

the ISM and shutting off the star formation) is a central focus. We attack this problem by using WISE and NVSS to define a sample of extremely luminous, highly obscured objects dominated by AGN luminosity, then use high resolution radio imaging with ALMA, VLA and VLBA to look for signatures of interaction between the radio jets and the host ISM. With ALMA we will be able to map transitions up the CO ladder from CO (2-1) to CO (14-13) to constrain the total gas masses, the dynamics of the gas (including outflows) at high spatial resolution, the contributions of AGN-excited XDRs to the CO excitation, and the structure of the molecular medium relative to the jets.

Paul Martini (Ohio State)

Daniel Dicken (IAS France)
Thaisa Storchi-Bergmann (UFRGS Brazil)

The Dust Dichotomy in Early-Type Galaxies

A surprisingly large number of early-type galaxies are observed to have circumnuclear dust, yet the origin of this dust remains a mystery. Two origins have been proposed to explain the dust: creation in winds by cool, evolved stars and the accretion of gas-rich satellites. We present multi-wavelength observations of a large sample of nearby, early-type galaxies that illustrate a pronounced dust dichotomy between dusty, early-type galaxies classified as AGN and dust-poor, inactive galaxies. Dust model fits to this well-matched and representative sample indicate that the typical dust mass is consistent with satellite accretion, yet this explanation appears to require a surprisingly high merger rate.

Phil Nelson (Concord University)

Phillip Nelson (Concord University)
John Simonetti (Virginia Tech)
Brian Dennison (UNC Asheville)

The Arcminute Morphology of the WIM Toward the Local Perseus Arm of the Galaxy as Seen in H-alpha and SII

We used the Virginia Tech Spectral-Line Imaging Camera (SLIC) to observe Hα and SII λ6716,6731 emission in the warm ionized interstellar medium (WIM) toward the Local Perseus Arm. We obtained a series of images, each of which is 10°-wide, and has arcminute-resolution. The images show three basic types of structures — compact clouds with diameters greater than several degrees, those that are 1° or less in diameter, and extended filaments which span several degrees in length but have thicknesses of only a few tens of arcminutes. The data show that [SII]/Hα ratios are, on average, nearly six times higher in the filaments than in the clouds, which indicates that emission from collisionally excited, singly-ionized S^+ is the dominant emission source within the filaments. In clouds, the lower [SII]/Hα values are evidence that the Hα recombination line of photoionized hydrogen dominates.

Kimberly Scott (NRAO)

Z-Spec Team
HerMES Collaboration

Redshift Determination and CO Line Excitation Modeling for the Multiply Lensed Galaxy HLSW-01

We report on the redshift measurement and CO line excitation of HERMES J105751.1+573027 (HLSW-01), a strongly lensed submillimeter galaxy discovered in Herschel/SPIRE observations as part of the Herschel Multi-tiered Extragalactic Survey (HerMES). HLSW-01 is an ultra-luminous galaxy with an intrinsic far-infrared luminosity of $L_{\rm FIR} = 1.4 \times 10^{13}\,L_{\rm sun}$, and is lensed by a massive group of galaxies into at least four images with a total magnification of $\mu = 10.9 \pm 0.7$. With the 100 GHz instantaneous bandwidth of the Z-Spec instrument on the Caltech Submillimeter Observatory, we robustly identify a redshift of $z = 2.958 \pm 0.007$ for this source, using the simultaneous detection of four CO emission lines ($J = 7 \rightarrow 6$, $J = 8 \rightarrow 7$, $J = 9 \rightarrow 8$, and $J = 10 \rightarrow 9$). Combining the measured line fluxes for these high-J transitions with the $J = 1 \rightarrow 0$, $J = 3 \rightarrow 2$, and $J = 5 \rightarrow 4$ line fluxes measured with the Green Bank Telescope, the Combined Array for Research in Millimeter Astronomy, and the Plateau de Bure Interferometer, respectively, we model the physical properties of the molecular gas in this galaxy. We find that the full CO spectral line energy distribution is described well by warm, moderate-density gas with $T_{\rm kin}$ = 86-235 K and $n_{\rm H_2}$ = 1.1-3.5 $\times 10^3\,{\rm cm}^{-3}$. However, it is possible that the highest-J transitions are tracing a small fraction of very dense gas in molecular cloud cores, and two-component models that include a warm/dense molecular gas phase with $T_{\rm kin} \sim 200\,{\rm K}$, $n_{\rm H_2} \sim 10^5\,{\rm cm}^{-3}$ are also consistent with these data. Higher signal-to-noise measurements of the $J_{\rm up} \geq 7$ transitions with high spectral resolution, combined with high spatial resolution CO maps, are needed to improve our understanding of the gas excitation, morphology, and dynamics of this interesting high-redshift galaxy.

Al Wootten (NRAO)

K. S. Scott (NRAO)
J. Wagg (ESO)
T. Wiklind (Joint ALMA Observatory)
A. Leroy (NRAO)
A. Peck (NRAO)

CII Line Emission in Massive Star-forming Galaxies at $z = 4.7$

We present Atacama Large Millimeter/submillimeter Array (ALMA) observations of the [CII] 157.7μm fine structure line and thermal dust continuum emission from a pair of gas-rich galaxies at $z = 4.7$, BR1202-0725. This system consists of a luminous quasar host galaxy and a bright submm galaxy (SMG), while a fainter star-forming galaxy is also spatially coincident within a $4''$ (25 kpc) region. All three galaxies are detected in the submm continuum, indicating FIR luminosities in excess of 10^{13} $L_\odot$ for the two most luminous objects. The SMG and the quasar host galaxy are both detected in [CII] line emission with luminosities, $L_{\rm [CII]} = (10.0 \pm 1.5) \times 10^9$ $L_\odot$ and $L_{\rm [CII]} = (6.5 \pm 1.0) \times 10^9$ $L_\odot$, respectively. We estimate a luminosity ratio, $L_{\rm [CII]}/L_{\rm FIR} = (8.3 \pm 1.2) \times 10^{-4}$

for the starburst SMG to the North, and $L_{[\mathrm{CII}]}/L_{\mathrm{FIR}} = (2.5 \pm 0.4) \times 10^{-4}$ for the quasar host galaxy, in agreement with previous high-redshift studies that suggest lower [CII]-to-FIR luminosity ratios in quasars than in starburst galaxies. The third fainter object with a flux density, $S_{340GHz} = 1.9 \pm 0.3$ mJy, is coincident with a Ly-α emitter and is detected in *HST* ACS F775W and F814W images but has no clear counterpart in the H-band. Even if this third companion does not lie at a similar redshift to BR1202-0725, the quasar and the SMG represent an overdensity of massive, infrared luminous star-forming galaxies within 1.3 Gyr of the Big Bang.