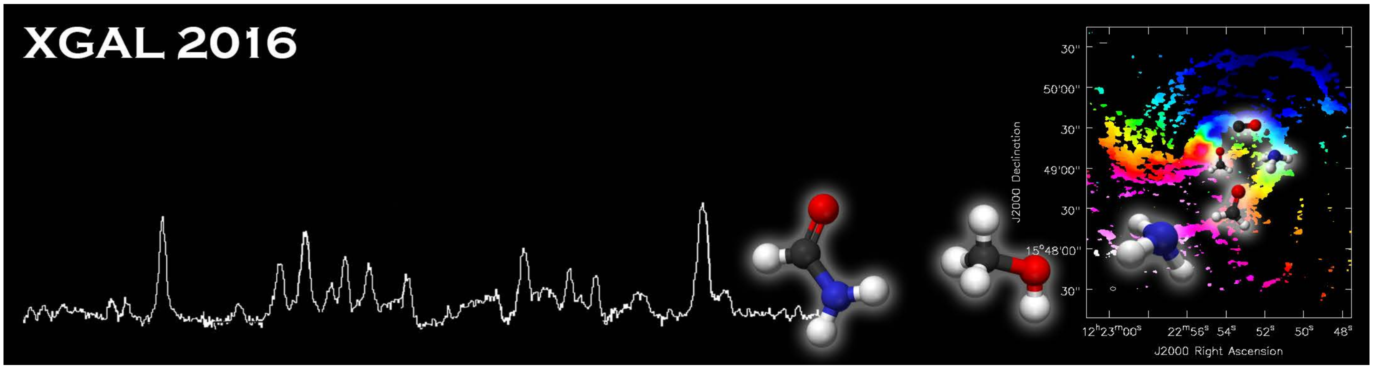

Molecular Gas in Galactic Environments Abstracts (Poster)

Charlottesville, Virginia, USA
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Ryo Ando (The University of Tokyo)

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Molecular Absorption and Emission Lines as the Powerful Probes of Heating Mechanisms of Interstellar Gases: From Diffuse Gases to Starbursts

We utilize molecular lines as discerning the heating sources of interstellar media (ISM) in two contrasted ways. Firstly, in search of molecular absorption systems toward ALMA calibrator sources, we have found HCO absorption lines toward two quasars. These detections illustrates that the Galactic diffuse ISM captured on the lines-of-sights are illuminated by ultraviolet radiation from distant massive stars. Molecular absorption studies should be more powerful in unveiling the chemistry in extragalactic sources. Secondly, we have detected various kinds of molecular emission lines in the nearby starburst galaxy NGC253 in ALMA Band 7 (0.8 mm). For the first time we resolved the central region of NGC253 into several star-forming regions of 10 pc scales. With the utilization of HNC vibrationally excited lines and other wavelength observation data, we have not only distinguished the environmental characteristics between these regions, but also diagnosed the heating sources of them. Despite in the center of the starburst, some regions are implied to be dominantly heated by mid-sized stars, rather than massive ones. Synergy of the observations of molecular absorption and emission lines in galaxies will greatly improve our comprehension of the heating mechanisms of ISM.

Loreto Barcos-Munoz (University of Virginia)

Adam Leroy (OSU)
Aaron Evans (UVa NRAO)
Eric Murphy (NRAO)
et al

A High Resolution, Unobscured View of the Active Regions in (Ultra) Luminous Infrared Galaxies from a VLA 33 GHz Survey

I will present a new survey of 33 GHz radio continuum emission from local U/LIRGs carried out using the Karl G. Jansky Very Large Array (VLA). This is the first such survey and it combines high resolution, good sensitivity, and multi-configuration observations that have sensitivity to emission on all spatial scales. (Ultra) luminous infrared galaxies host some of the most extreme star-forming environments in the local universe, with large reservoirs of molecular gas and dust concentrated in the central few kpc. Our VLA observations allow us to see through the dust in these systems to resolve the sizes of their active regions, which is essential to understand the true distribution of star formation and physical properties of the gas in these extreme systems. I will present the best size measurements to date of the active regions for our 22 targets. I will show what these sizes imply about gas volume and surface density, and infrared luminosity surface densities. I will also lay out the physical implications of these values for the strength of star formation and feedback (especially radiative feedback) in extreme environments.

Alejandro Barrientos (ALMA Universidad Tecnica Federico Santa Maria)

Ricardo Nanculef (Universidad Tecnica Federico Santa Maria)
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Natalia Gonzalez (Universidad Tecnica Federico Santa Maria)
Andres Ferreira (Universidad Tecnica Federico Santa Maria)

Machine Learning Approaches for Classification of Astrochemical Spectra

Astronomical spectroscopy is a field that has been growing for a number of years, analyzing the features of molecular spectral lines from astronomical data cubes provides insight to the composition of our universe. With the arrival of state-of-the-art radiotelescopes like ALMA, the size of the data cubes will be constantly growing in time. This is why we believe that some automatic analysis methods will be required to ease the astrochemists work. We would like, in some way, to recreate the experiment performed by Madden et.al in 2008 by training a molecular spectrum classification learner, using synthetic spectra, and validate it using radio astronomical data cubes from ALMA Band 7 Science Verification data. A summary of related projects is presented, and also a brief list of the astronomical complexities surrounding the nature of a molecular spectrum. A naive model is considered to start the problem and two Machine Learning methods are tested for the task of classifying molecular spectra, Support Vector Machines and Neural Networks, results for SVM resulted in accuracy of over 90 percent with the basic model. The Neural Network approach, provided even better results.

Ashley Bemis (McMaster University)

Christine Wilson (McMaster University)

Investigating Dense Gas and Star Formation in the Antennae Galaxies (NGC 4038/39) using ALMA

The Antennae is the nearest (22 Mpc) pair of interacting galaxies and shows evidence of recent, wide-spread star formation. We are studying the relationship between dense gas and star formation in the Antennae by comparing high-resolution ALMA observations of dense gas tracers (HCN, HCO+, and HNC) to the 70 micron image from the Herschel Space Observatory. A recent study of the Antennae by Bigiel et al. 2016 (accepted) using CARMA has compared the emission of these dense gas tracers in the brightest regions of the overlap region and two nuclei. With the higher sensitivity of ALMA, we are able to probe additional fainter regions in the dense gas tracers and compare the total recovered flux of these two studies. We combine the ALMA data with OVRO CO data to derive the star formation efficiencies and compare with dense gas fractions and dense gas star formation efficiencies.

Andrew Burkhardt (University of Virginia)

Niklaus Dollhopf (University of Virginia)
Joanna Corby (University of Virginia)
P Brandon Carroll (California Institute of Technology)
Chistopher Shingledecker (University of Virginia)
Ryan Loomis (Harvard University)

CARMA Observations of L1157: Complex Chemistry of Shock Tracers within Outflows

Shocks have been found to be ubiquitous throughout the interstellar medium and in star forming regions. Therefore, determining the underlying formation chemistry of shock tracers is crucial to understanding what the enhancement of these species actually imply. L1157, a molecular dark cloud with an embedded Class 0 protostar possessing a bipolar outflow, is an excellent source for studying shock chemistry, including grain-surface chemistry prior to shocks, and post-shock, gas-phase processing. Prior to shock events an estimated ∼2000 and 4000 years ago, temperatures were too low for most complex organic molecules to undergo thermal desorption. Thus, the shocks should have liberated these molecules from the ice grain-surfaces *en masse*. Here, we present high spatial resolution (∼3 arcsec) maps of CH_3OH, HNCO, HCN, and HCO^+ in the southern portion of the outflow containing B1 and B2, as observed with CARMA. The HNCO maps are the first interferometric observations of this species in L1157. The maps show distinct differences in the chemistry within the various shocked regions in L1157B. This is further supported through constraints of the molecular abundances using the non-LTE code RADEX. We find the east/west chemical differentiation in C2 may be explained by the contrast of the shockś interaction with either cold, pristine material or warm, previously-shocked gas, as seen in enhanced HCN abundances. In addition, the enhancement of HNCO abundance toward the the older shock, B2, suggests the importance of high-temperature O-chemistry in shocked regions.

S Michelle Consiglio (UCLA)

J -Q Song (UCLA)
J -H Zhao (CfA)
J L Turner (UCLA)

Gas and Star Formation in NGC 2403

NGC 2403 is a nearby dwarf spiral galaxy. Like many dwarf galaxies, it is relatively molecular gas poor, yet it has extremely large star-forming regions. With new CO images from the Submillimeter Array and existing VLA continuum data, we examine the relation of gas and star formation in this galaxy on 4" scales.

Joanna Corby (University of Virginia)

Brett McGuire (NRAO)
Anthony Remijan (NRAO)
Eric Herbst (University of Virginia)
Dominique Malfucci (University of Virginia)
Alexei Ivlev (MPE)

Complex Organic Chemistry in the Diffuse and Translucent ISM

Diffuse and translucent clouds constitute a significant reservoir for a galaxyś gas, and observing the structure and chemistry of these clouds is essential for understanding the processing of gas within galaxies. Data collected with the GBT reveal that the molecular complexity within Galactic diffuse and translucent clouds is significantly greater than previously known, with complex organic molecules (COMs) including CH3OH, HC3N, CH3CN, CH3CHO, and NH2CHO present. We discuss abundance patterns with cloud conditions and galactocentric distance. A few of the COMs are believed to form efficiently only on dust grain surfaces, however grain surface organic chemistry has is not been considered in this medium due to the low densities and high UV fluxes, which should prevent the formation of ice mantles. Furthermore, VLA images of the COMs reveal that the translucent clouds contain a clumpy structure. We discuss this result in the context of recent theoretical predictions for the density structure of the ISM (Tsytovich et al. 2014) and explore implications for the density structure, radiative conditions, and molecular chemistry in these systems.

Niklaus Dollhopf (University of Virginia)

Jennifer Donovan Meyer (National Radio Astronomy Observatory)

Formaldehyde in Absorption: Tracing Molecular Gas in Early-Type Galaxies

Early-Type Galaxies (ETGs) have been long-classified as the red, ellipsoidal branch of the classic Hubble tuning fork diagram of galactic structure. In part with this classification, ETGs are thought to be molecular and atomic gas-poor with little to no recent star formation. However, recent efforts have questioned this ingrained classification. Most notably, the ATLAS^{3D} survey of 260 ETGs within $\sim$40 Mpc found that 22% contain CO, a common tracer for molecular gas. The presence of cold molecular gas also implies the possibility for current star formation within these galaxies. Simulations do not accurately predict the recent observations and further studies are necessary to understand the mechanisms of ETGs.

CO traces molecular gas starting at densities of $\sim 10^2$ cm^{-3}, which makes it a good tracer of bulk molecular gas, but does little to constrain the possible locations of star formation within the cores of dense molecular gas clouds. Formaldehyde (H_2CO) traces molecular gas on the order of $\sim 10^4$ cm^{-3}, providing a further constraint on the location of star-forming gas, while being simple enough to possibly be abundant in gas-poor ETGs. In cold molecular clouds at or above $\sim 10^4$ cm^{-3} densities, the structure of formaldehyde enables a phenomenon in which rotational transitions have excitation temperatures driven below the temperature of the cosmic microwave background (CMB), $\sim$2.7 K. Because the CMB radiates isotropically, formaldehyde can be observed in absorption, independent of distance, as a tracer of moderately-dense molecular clouds and star formation.

This novel observation technique of formaldehyde was incorporated for observations of twelve CO-detected ETGs from the ATLAS^{3D} sample, including NGC 4710 and NGC 1266, to investigate the presence of cold molecular gas, and possible star formation, in ETGs. We present spectral-line and continuum images from the Very Large Array, used in its C-array configuration, of the $J = 1_{1,0} - 1_{1,1}$ transition of formaldehyde towards these sources. We report our preliminary results here.

Niklaus M. Dollhopf gratefully acknowledges the support of the National Radio Astronomy Observatory Summer Student REU Program sponsored by the National Science Foundation.

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Astrochemistry Simulated in Electron-irradiated CO2/NH3 Ices

Low energy secondary electrons are abundantly produced in astrophysical or planetary ices by the various ionizing radiation fields encountered in space environments, and may thus play a role in the radiation processing of such ices (Moore et al. 2005). One approach to simulate their astrochemical effect is to irradiate nanometer thick molecular solids of simple molecular constituents in ultra-high vacuum (UHV) with energy selected electron beams, and to monitor changes in film chemistry with surface analytical techniques (Arumainayagam et al. 2010). Of particular interest is the formation of HCN, which is a signature of dense gases in interstellar clouds, and is ubiquitous in the ISM. Moreover, the chemistry of HCN radiolysis products such as CN???? may be essential to understand of the formation of amino acids (Vera et al. 2014) and purine DNA bases. Here we present new results on the UHV irradiation of cryogenic (22 K) multilayer films of CO2 and NH3 with 70 eV electrons, leading to CN, and other new bond formations. Mass resolved electron stimulated desorption yields of cations and anions are recorded as a function of electron fluence. The prompt desorption of cationic reaction/scattering products (Huels et al. 2008) is observed at low fluence. Detected ions that suggest formation of new chemical species include C+2 , C2O+2, C2O+, CO+3 , C2O+3 or CO+4 from pure CO2, and N+,NH+, NH+2, NH+3, NH+4, N+2, N2H+ from pure NH3, and NO+, NOH+ from CO2/NH3 mixtures. Most saliently, increasing signals of new negative ion products desorbing during prolonged irradiation of CO2/NH3 films included C2 , C2H, C2H2 , as well as CN, HCN and H2CN. The identification of product ions was aided by using 13CO2 and 15NH3 isotopes. The chemistry induced by electrons in pure films of CO2 and NH3, as well as mixtures with composition ratios (3:1), (1:1), and (1:3), was also studied by X-ray photoelectron spectroscopy (XPS). The XPS results show that electron irradiation of CO2/NH3 mixed films produces new chemical species containing C=O, OH, CC, CO, C=N and N=O bonds. (Work funded by NSERC).

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David Frayer (NRAO)

GBT Observations and Instrumentation at 3mm Wavelengths

The Robert C. Byrd Green Bank Telescope (GBT) is the world's largest fully steerable radio telescope. The active surface of the GBT enables efficient observations within the 3mm atmospheric window. The GBT is, by far, the most sensitive 3mm single-dish telescope in the world and has similar a point-source sensitivity as ALMA at 3mm wavelengths. We present recent science highlights from the GBT at 3mm wavelengths and discuss the status of the current 3mm instrumentation programs for the GBT.

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C M Bradford (JPL)
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SuperSpec: A New Technology for Sub/Millimeter Broadband Spectroscopy of High-Redshift Galaxies

SuperSpec is a new spectrometer-on-a-chip technology that we are developing for moderate resolution (R = 100 - 500), large bandwidth (1.65:1), submillimeter and millimeter-wave multi object spectroscopy. It will enable observations of [CII] in high-redshift galaxies and multiple mid-J transitions of CO near the peak of the CO spectral line energy distributions of star-forming galaxies. Thus, observations with SuperSpec will measure redshifts of dust-continuum-detected galaxies and characterize their excited molecular gas contents. SuperSpec uses a filter bank architecture with a series of half-wave resonators fabricated with superconducting transmission lines coupled to lumped-element titanium nitride kinetic inductance detectors. We report on the SuperSpec design, science capabilities of SuperSpec, and laboratory prototype SuperSpec measurements, which have already reached noise equivalent powers of 1.4×10^{-17} W $\mathrm{Hz}^{-1/2}$.

Jason Glenn (University of Colorado Boulder)

N Rangwala (NASA Ames)
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C Wilson (McMaster University)

Morphology and Kinematics of the Warm Nuclear Molecular Gas in NGC 6240

Herschel Space Observatory observations of mid to high-J transitions of CO in star-forming galaxies have revealed that the majority (90%) of the CO luminosity arises from a warm component of the molecular gas. It is not yet clear what morphological and kinematic relationship this warm molecular gas shares with cool molecular gas probed with low-J CO observations, which comprises the bulk of the molecular gas mass, and very warm molecular gas probed directly with vibrational transitions of H_2. The merging, double-nucleus, luminous infrared galaxy NGC 6240 displays very bright H_2 and CO emission relative to the far-infrared continuum emission and serves as an excellent case study for investigating the excitation, morphology, and kinematics of nuclear molecular gas. We have obtained new ALMA CO J = 3 - 2 and 345 GHz continuum imaging and have pending ALMA CO J = 6 - 5 and SOFIA H_2 (S(1) 17.0 μm and S(2) 12.3 μm) observations that will enable us to compare the warm gas probed by these different tracers. We present the observations obtained to date, describe pending observations, and describe early results, which include the detection of a new nuclear continuum source in NGC 6240.

James Higdon (Georgia Southern University)

Sarah J U Higdon (Georgia Southern University)
Sergio Martin (Joint ALMA Observatory)
Richard J Rand (University of New Mexico)

Star Formation and the Molecular ISM in Ring Galaxies

Ring galaxies provide striking examples of the ability of collisions to transform the morphology and star forming activity of a spiral. The interaction generates one or more outwardly traveling orbit-crowded rings that "snow plow the disks ISM as it propagates while triggering star formation via large-scale gravitational instabilities. The confinement of 90% of the disks ISM in the rings of these systems for > 100 Myr also provides a unique environment to study the effects of massive stars on its physical state. Our current investigations of the Cartwheel and AM0644-741, two large and gas rich ring galaxies, find their robustly star forming rings to be characterized by extremely low molecular gas fractions and highly peculiar star formation laws, in which massive star formation and cold molecular gas appear to be uncorrelated. We will discuss various interpretations of these results and describe new work utilizing infrared dust emission and ALMA HCN/HCO+ obserations to assay the rings molecular ISM and its relation with massive star formation.

Thomas Hughes (University of Valpara)

The CO Emission from H-ATLAS Galaxies up to Z=0.4

We study the molecular gas content in a large sample of 70 galaxies at $0.03 < z < 0.4$ selected from the *Herschel* Astrophysical Terahertz Large Area Survey via ALMA ^{12}CO(10) and ^{13}CO(10) observations. We also detect [CII] 158 micron emission in a subsample of these systems. By comparing the ^{12}CO(1-0) and [CII] line emission to the predictions of PDR models, we determine the averaged gas density, $< n >$, and far-UV radiation field, $< G_0 >$, interacting with the star-forming gas, allowing us to constrain the evolution of these quantities as a function of redshift. Since a fraction of the CO line emission will arise from non-PDR inner colder regions, we use a stacking technique to estimate upper limits to the optically-thin ^{13}CO line emission and thus gain an important constraint on the molecular gas reservoirs and the uncertainties in the physical conditions of the PDR gas. From the CO-based H_2 gas masses, [CII]-based HII masses and stellar masses from ancillary data, we determine the gas fractions for these sources and track their evolutionary progress. These results will be crucial for the interpretation of imminent ALMA observations of higher redshift galaxies.

Joyce Ivory (NRAO)

Lyndele VonSchill (NRAO ODI)

The National Astronomy Consortium

The National Radio Astronomy Observatory's National Astronomy Consortium (NAC) Student program features a cohort-based year long student research experience for undergrads. The NAC program was designed to broaden participation in full-spectrum astronomy for underrepresented and under-served students. The NAC model is distinguished by its intensive mentoring model emphasizing; career long relationships with peers and mentors, professional development, collaboration, and community. The NAC program along with its growing network of HBCUs, HSIs, and MSIs partners are building a legacy of undergrad to grad to postdoc+ pipeline for students who are other wise not in the traditional REU pipeline.

Karen Knierman (Arizona State University)

Paul Scowen (Arizona State University)
Chris Groppi (Arizona State University)
Kelsey Johnson (University of Virginia)

Tidal Tales of Minor Mergers: Molecular Gas in the Tidal Tails of Minor Mergers

While major mergers and their tidal debris are well studied, equal mass galaxy mergers are relatively rare compared to minor mergers (mass ratio <0.3). Minor mergers are less energetic than major mergers, but more common in the observable universe, and thus likely played a pivotal role in the formation of most large galaxies. Tidal debris regions have large amounts of neutral gas but a lower gas density and may have higher turbulence. We use star formation tracers such as young star cluster populations and H-alpha and CII emission to determine the different factors that may influence star formation in tidal debris. These tracers were compared to the reservoirs of molecular and neutral gas available for star formation to estimate the star formation efficiency (SFE). The SFR in tidal debris can reach up to 50% of the total star formation in the system. The SFE of tidal tails in minor mergers can range over orders of magnitude on both local and global scales. From the tidal debris environments in our study, this variance appears to stem from the formation conditions of the debris. Current surveys of the 2.12 micron line of molecular hydrogen, CO(1-0), and HI for 15 minor mergers, are providing a larger sample of environments to study the threshold for star formation that can inform star formation models, particularly at low densities.

Mark Lacy (NRAO)

Steve Croft (UC Berkeley)
Chris Fragile (College of Charleston)

CO observations of Minkowski's Object

We present ALMA CO observations of Minkowski's Object, a dwarf starforming galaxy that appears to be interacting with a radio jet from a nearby giant elliptical. Minkowski's Object has been proposed as an archetype for jet-induced star formation. With these ALMA observations we will constrain the molecular gas content, its surface mass density and its dynamics with the aim of testing the hypothesis that the current burst of star formation has been triggered by shocks induced by the passage of the radio jet through the galaxy.

Tsz Kuk Daisy Leung (Cornell University)

Dominik A Riechers (Cornell University)

A Massive Molecular Gas Reservoir in the z=2.221 Type-2 Quasar Host Galaxy SMMJ0939+8315 lensed by the Radio Galaxy 3C220.3

An evolutionary link between submillimeter-bright galaxies (SMGs) and quasars at the peak epoch of star formation has been proposed in light of recent observations, suggesting massive galaxies transition from a short-lived star-burst phase to an unobscured quasar phase as they evolve. I will discuss the key findings in our recent paper (Leung & Riechers 2016), placing an unusually bright type-2 quasar host SMG – SMMJ0939+8315 – in the context of the aforementioned paradigm. I will conclude with our newly obtained observations of the CO(J=1-0) line emission toward SMMJ0939+8315, making it only the second type-2 quasar with direct constraints on the cold molecular gas content and dynamics and allowing us to make inroads into addressing the question of how the different galaxy populations are related and responsible for the build-up of stellar mass and supermassive black hole in the universe, free from excitation biases.

Rebecca Levy (University of Maryland College Park)

Alberto D Bolatto (University of Maryland College Park)
Tony Wong (University of Illinois, Urbana-Champaign)
the EDGE Collaboration

Velocity Field Structure in the EDGE Galaxies

The CARMA Extragalactic Database for Galaxy Evolution (EDGE) survey imaged ^{12}CO(1-0) in over 170 nearby spiral galaxies. One of its objectives is to study the kinematics of the molecular components of these systems. The EDGE galaxies were selected from the larger Calar Alto Legacy Integral Field Area (CALIFA) survey IFU sample, which provides full spectral information on their stellar and ionized gas components. These surveys provide a uniquely powerful way to study the feedback mechanisms affecting the evolution of these galaxies by using the large-scale kinematics of the molecular, stellar, and ionized components in tandem. By modeling the bulk rotation of a galaxy then subtracting it, the residual velocity fields can be examined. This will allow us to look for anomalous velocity structures, such as molecular outflows and counter-rotating cores, which are indicative of a starburst, merger, or AGN. We present the EDGE sample and the results of the rotation curve modeling and subtraction.

Julia Lukens (Wellesley College)

Jane Zhu (Wellesley College)
Esther B hler (University of Bremen)
Petra Swiderek (University of Bremen)
Chris Arumainayagam (Wellesley College)

Ammonia Radiolysis: An Interstellar Source of Nitrogen

The goal of our experiments is to elucidate the role of low-energy electrons in the synthesis of prebiotic molecules in cosmic (interstellar, planetary, and cometary) ices. Ammonia is of particular interest because it is the most abundant nitrogen-containing compound in the interstellar medium (ISM). Cosmic ices are subject to many forms of high-energy radiation (e.g., cosmic rays and x-rays). The resulting cascade of low-energy (< 20 eV) secondary electrons is thought to initiate radiolysis reactions in the condensed phase.

In our experiments, we simulate these cosmic processes in an ultrahigh vacuum chamber by depositing thin films of condensed ammonia on a metal substrate and exposing them to electrons with well-defined energy. Using post-irradiation temperature-programmed desorption (TPD) experiments, we have found evidence for the electron-induced formation from ammonia of hydrazine (N2H4), diazene (N2H2), cyclotriazane/triazene (N3H3) and triazane (N3H5). We have investigated the reaction yield dependence on film thickness, irradiation time, incident current, electron energy, and metal substrate. These results provide a basis from which we can begin to understand the mechanisms by which ammonia can form more complex species in cosmic ices.

Naslim Neelamkodan (ASIAA)

Toshikazu Onishi (Osaka Prefecture University)
Ciska Kemper (ASIAA)
Akiko Kawamura (NAOJ)
Oscar Morata (ASIAA)
Kazuki Tokuda (Osaka Prefecture University)

Molecular Cloud Properties of N55 in the LMC with ALMA Observations

We have obtained ALMA observation of molecular gas in 12CO(1-0) and 13CO(1-0) toward molecular cloud N55 in the LMC. We are doing a detailed study of molecular gas physical conditions, to understand how the cloud properties of N55 differ from our Galaxy. N55 is a comet shaped molecular cloud inside the largest Supergiant Shell LMC 4 and excited by the star cluster LH 72. LMC 4 is formed by ovelapping shells and N55 is associated with one of the overlapping shells. Here, we report the study of size, mass, linewidths and luminosities of the 12CO clumps and comparison with the Orion molecular cloud. To study the complex molecular cloud in N55, we decompose the 12CO(1-0) and 13CO(1-0) emission into several clumps using a decomposition algorithm. We report the size-linewidth relation, virial mass-luminosity relation and X_{CO} factor toward this cloud and comparison with the Orion molecular cloud.

Rosita Paladino (INAF Osservatorio di Radioastronomia)

Giant Molecular Clouds Properties in Nearby Galaxies

A wide range of physical processes is involved in massive star formation: it is now clear that the large-scale star formation rate is determined both by physical processes on large scale (such as the accretion of gas onto disks from satellite objects and from the intergalactic medium), and by processes operating on cloud scales (from the cooling of the gas on kpc scales, to the formation of molecular clouds on pc scales, and the subsequent fragmentation and accretion of this molecular gas to form denser structures). The key processes lie on the boundary between these physical scales. Nearby galaxies provide the ideal laboratory to investigate them, allowing the study of galaxy processes on large scales, while still being close enough to reveal the local details, if high resolution and sensitivity are achieved.

Detailed images of the molecular distribution in nearby galaxies, which are so far few exceptions, thanks to ALMA unprecedented capabilities will become the rule. It will be possible to address important questions, such as what is the importance of local and global effects in triggering star formation, which is the role of magnetic fields, or how do environmental conditions or galaxy properties influence star formation.

I will present simulations of ALMA observations of a giant molecular cloud located in external galaxies, showing how far it will still be possible to resolve such structures and study their dynamical properties. And I will present a project currently being observed with ALMA, which could be a prototypical example of detailed star formation studies along the bars of nearby galaxies.

Zoe Peeler (Wellesley College)

Michael C Boyer (Clark University)
Chris Arumainayagam (Wellesley College)

The Role of Low-Energy (< 20 eV) Electrons in Astrochemistry

In the interstellar medium, UV photolysis of ice mantles encasing dust grains is thought to be the mechanism that drives the synthesis of complex molecules. The source of this reaction-initiating UV light is assumed to be local because externally sourced UV radiation cannot penetrate the ice-containing dark, dense molecular clouds. Specifically, high-energy cosmic rays penetrate and ionize the molecular clouds, generating secondary electrons. Hydrogen molecules, present within these dense molecular clouds, are excited in collisions with these secondary electrons. The UV light emitted by these electronically excited hydrogen molecules is generally thought to photoprocess interstellar ice mantles to generate complex molecules. In addition to producing UV light, the large numbers of low-energy (< 20 eV) secondary electrons, produced by cosmic rays, can also directly initiate radiolysis reactions in the condensed phase. We hypothesize that cosmic-ray induced low-energy electron processing of interstellar ices may occur via three mechanisms: (1) the interaction of cosmic rays with gaseous molecular hydrogen produces low-energy electrons that can interact with the surface (top few molecular layers) of cosmic ices, (2) the interaction of cosmic rays with molecules within cosmic ices generate a cascade of low-energy electrons that can interact with the surface and the bulk of the ice mantles, (3) the interactions of cosmic rays with the dust grain beneath the ice mantle engender low-energy electrons that can interact with the bottom ice layers in contact with the dust grain. The goal of our studies is to understand the low-energy electron-induced processes that occur when high-energy cosmic rays interact with interstellar ices. Using post-irradiation temperature-programmed desorption (TPD) and infrared reflection absorption spectroscopy (IRAS), we have investigated the radiolysis initiated by low-energy (5-20 eV) electrons in condensed methanol, ammonia, and water at 90 K under ultrahigh vacuum (1109 Torr) conditions. Our experimental results suggest that low-energy electron-induced condensed phase reactions may contribute to the interstellar synthesis of complex molecules previously thought to form exclusively via UV photons.

Kazimierz Sliwa (Max Planck Institute for Astronomy)

Christine Wilson (McMaster University)

Molecular Gas Properties in Local Luminous Infrared Galaxies

Galaxy mergers are an important process of galaxy evolution, however, the merger process is not well understand. The majority of luminous infrared galaxies (LIRGs) in the local universe are mergers of gas-rich galaxies. The merger event funnels the molecular gas towards the central kiloparsec, compressing the gas, and triggering an extreme starburst, making LIRGs the perfect laboratory for studying extreme modes of star formation. We use high-resolution ^{12}CO and ^{13}CO observations from the SMA, CARMA and ALMA of a sample of 6 LIRGs that span a large range of merger stages to look for an evolutionary trend in molecular gas physical properties. The molecular gas physical conditions such as temperature, volume and column densities are constrained using a radiative transfer code combined with a Bayesian likelihood method. We find that the early/intermediate stage mergers contain, on average, denser ($> 10^{3.0}$ cm^{-3}), colder (< 30K) molecular gas than late stage mergers. We also measure the CO-to-H_2 conversion factor, $\alpha_{\rm CO}$, of the sample and find no trend with merger stage. Finally, we find unusually large [^{12}CO]/[^{13}CO] abundance ratios (> 100) except in our earliest merger stage LIRG, Arp 55 ([^{12}CO]/[^{13}CO] ~ 30). In addition to the sample analysis, we will present new ALMA Cycle 2 CO observations of the 2nd nearest Ultra LIRG, IRAS 13120-5453 and VV 114.

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Shuro Takano (College of Engineering Nihon University)
Tac Nakajima (The Solar-Terrestrial Environment Laboratory Nagoya University)
Nanase Harada (Academia Sinica Institute of Astronomy and Astrophysics)

SiO Multi-transition Observations and Analyses toward the Strongly-shocked Dense Gas in the Center of NGC 1068

We will present the result of SiO multi-transition observations of ALMA Cycle 2 toward the Seyfert 2 galaxy NGC 1068. We obtained SiO $J = 2-1$, $3-2$, $5-4$ and $6-5$ as well as referential molecules including ^{13}CO $J = 2-1$ and CS $J = 5-4$ at $\sim 0.5arcsec$ (40 pc) spatial resolution in the central $r < 1$ kpc region.

SiO, one of the shocked tracer molecules, seems to be concentrated on the eastern knot (E-knot) on the circumnuclear disk (CND) around the nucleus of NGC 1068 and has an elongated shape (especially visible in SiO(3-2), which has the highest spatial resolution of $0.4arcsec$) along the direction of the non-thermal jet traced by the 3-mm continuum emission. We also found a locally high CS/^{13}CO region (the CS(5-4)/^{13}CO(2-1) flux ration exceeds 2) at northeast of the CND, which overlaps with ionized outflow cone.

For revealing the origin of SiO, we conducted LTE analyses via rotational diagrams of SiO and 13CO, and non-LTE ones via RADEX using only 4-transition SiO lines at the E-knot. As a result, SiO seems to be enhanced at the E-knot ([SiO]/[^{13}CO] $\sim 10^{-3}$) compared with typical starburst galaxies and ULIRGs ([SiO]/[^{13}CO] $\sim 10^{-5} - 10^{-4}$), and to be located at dense ($10^4 - 10^5$ cm^{-3}) and high kinetic temperature ($300 - 1000$ K) gas. Taking these results together, it is suggested that SiO is originated from the shocked gas on the CND interacting with jet and/or outflow from the AGN.

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ALMA Observations of ^{12}CO(3-2), HCO+(4-3) and 860-micron Continuum in the Nearby Galaxy NGC1808

In starburst galaxies, it is believed that gas inflow toward the galaxy center is causing explosive star formation. In order to elucidate the distribution of molecular gas, sensitive observations are required.

NGC 1808 is a nearby (11 Mpc), barred starburst galaxy with polar dust lanes from the nuclear 500-pc region associated with a gas outflow.Previous observations have revealed that molecular gas is concentrated in the galactic central region, although detailed structure could not be resolved.To goal of our study is to understand the connection between the molecular gas distribution, starburst, and outflow with high-resolution observations.

We present preliminary results of our mosaic observations of NGC 1808 using the Atacama Large Millimeter/submillimeter Array (ALMA) as part of our cycle 2 project.^{12}CO (3-2) images reveal a molecular-gas ring of radius 500 pc, and nuclear spiral structure associated with streaming motions between the galaxy center and the ring.The HCO+ (4-3) emission and 860-micron continuum is detected only from compact sources.Especially, in galaxy center (within 100pc), molecular gas is concentrated, and it was detected strongly in HCO+(4-3) and 860-micron continuum. Non-circular, streaming motions are revealed in the velocity field.

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A statistical study of Giant Molecular Clouds in the Starburst Ring of NGC 1068 using ALMA

We present the first statistical study of physical and chemical properties of giant molecular clouds (GMCs) in the starburst ring of NGC 1068. This study is based on ALMA cycle 2 observations with a synthesized beam size of 1.4″ ($\sim$ 108 pc at a distance of 14.4 Mpc).

The central $\sim$ 1 arcmin diameter region of NGC 1068 has been mapped in the molecular emission lines including ^{13}CO(1-0), C^{18}O(1-0), CS(2-1) and CH_3OH(2-1). High sensitivity of ALMA allowed us to produce the 3-dimentional data cubes of these molecular lines with a high spectral resolution (1.5 km s^{-1}), which is essential for study of molecular gas in the disk regions of galaxies.We have identified high significance ($> 8\sigma$) 195 GMCs from the high velocity resolution ^{13}CO(1-0) data cube applying the CLUMPFIND algorithm. This is one of the largest samples of GMCs in galaxies constructed based on ^{13}CO(1-0) emission, and a GMC mass function at $\sim$ 100 pc resolution has been obtained in the starburst ring of NGC 1068 for the first time.

The typical size and line width of the identified GMCs are 100 pc and 10.0 km s^{-1}, respectively. We find that they tend to follow the known size to line-width relation of the Galactic GMCs. The averaged mass of the GMCs is $2.9 \times 10^6 M_\odot$ by assuming LTE, and their virial parameters (M(LTE)/M(vir)) show that the supercritical GMCs are preferentially found on the starburst ring, while the subcritical GMCs are mainly located outside of the ring.

The observed C^{18}O(1-0)/^{13}CO(1-0) intensity ratios are found to be fairly uniform among the identified GMCs. On the other hand, CS/^{13}CO ratios tend to be smaller at a larger distance from the bar end. In contrast, CH_3OH/^{13}CO ratios are smallest around the bar-end, and become larger along the spiral arms. In the bar-end, more active massive star-formation occurs, and therefore gas temperature becomes higher than spiral arms, suppressing the production of methanol in the bar-end. These results suggest that the chemical properties of molecular clouds on the GMC scales are affected by the $>$ kpc scale structures of the galaxies such as bar and spiral arms.

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Submillimetric Study of Nearby Galaxies: NGC 253, NGC 4945 and Arp 220

We present the first submillimetre line survey of extragalactic sources carried out by APEX. The surveys cover the 0.8 mm atmospheric window from 270 to 370GHz toward NGC253, NGC4945 and Arp220. We found in NGC 253, 150 transitions of 26 molecules. For NGC 4945, 136 transitions of 24 molecules, and 64 transitions of 17 molecules for Arp 220. Column densities and rotation temperatures have been determinate using the Local Thermodinamical Equilibrium(LTE) line profile simulation and fitting in the MADCUBA IJ software. The differences found in the 32S/34S and 18O/17O ratios between the GC and the starburst galaxies NGC 4945 and NGC 253 suggest that the gas is less processed in the latter than in the GC. The high 18O/17O ratios in the galaxies NGC 4945 and NGC 253 suggest also material less processed in the nuclei of these galaxies than in the GC. This is consistent with the claim that 17O is a more representative primary product than 18O in stellar nucleosynthesis (Wilson and Rood 1994); Also, we did a Multitransitions study of H3O+ at 307GHz, 364GHz, 388GHz and 396GHz. From our non-LTE analysis of H3O+ in NGC253 with RADEX we found that the collisional excitation cannot explain the observed intensity of the ortho 396 GHz line. Excitation by radiation from the dust in the Far-IR can roughly explain the observations if the H2 densities are relatively low. From the derived H3O+ column densities we conclude that the chemistry of this molecule is dominated by ionization produce by the starburst in NGC253 (UV radiation from the O stars) and Arp 220 (cosmic rays from the supernovae) and likely from the AGN in NGC4549 (X-rays); Finally, we report, for the first time, the tentative detection of the molecular ion HCNH+ (precursor of HCN and HNC) toward a galaxy, NGC4945, the abundance is much larger than the Galactic center in the Milky Way, abundance explain the claimed enhancement of HCN abundance in the AGN, due to the enhancement of the ionization rate by X-rays.

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Molecular Gas Depletion Times in Local Mergers: Bridging the Gap between Normal Galaxies and ULIRGs in the Schmidt-Kennicutt Relation

Normal star-forming galaxies and ULIRGs - both at low and high redshift - seem to form two distinct sequences in terms of gas content and SFR (the Schmidt-Kennicutt relation; Daddi et al. 2010b, Genzel et al. 2010), with ULIRGs characterized by much shorter molecular gas depletion times, probably caused by merger-induced turbulences (e.g. Teyssier 2010). We rely on CO(1-0) and CO(2-1) IRAM 30-m observations of a sample of 11 SDSS selected galaxy pairs to investigate the effect of moderate interaction on star formation activity. Through a robust calculation of the $alpha_{CO}$ conversion factor (Sargent et al. 2010) we obtain molecular gas masses and depletion times of these SDSS mergers. By comparing them with those of both normal galaxies with similar mass and redshift as well as with ULIRGs we can determine whether the SFR law is truly bimodal, or local mergers represent an intermediate class of sources which bridge the two sequences.

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High-resolution ALMA Imaging of Molecular Gas Close to the Supermassive Black Hole in M87

The proximity of M87 (3C 274), the archetypical giant elliptical radio galaxy at the centre of the Virgo cluster, presents a unique opportunity to investigate in detail the properties of the interstellar medium around a supermassive black hole (SMBH). Circumnuclear molecular gas in M87 was previously detected using single-dish observations. Now, ALMAś new long baseline capability allows the first detailed imaging of the molecular gas around M87ś SMBH on scales down to a few parsecs (few tens of milliarcseconds). We present ALMA Band 3 CO J=1-0 observations obtained at different angular resolutions in Cycles 1 and 3. The high spatial resolution (10-pc scale) imaging allows us to investigate, in unprecedented detail, the nature and origin of molecular gas residing within the sphere of influence of the SMBH.

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The Skeleton of the Milky Way

We present the identification of ten highly elongated filamentary molecular clouds, now termed Galactic B̈ones, some of which could potentially trace out the densest spines of the Milky Wayś spiral features (arms, spurs, feathers, and interarm structure). Given their extraordinary length, the Bones formation is likely governed by the gravity of the Galaxy, rather than by more local forces. All of our Bones have incredibly large aspect ratios, lie parallel to and within twenty parsecs of the physical Galactic mid-plane, and are well-correlated with global-log spiral fits to CO or HI in position-position-velocity space. We discuss our ongoing efforts to catalog Galactic Bones and connect them with recent numerical simulations of high-contrast filament formation in the Galactic plane. We also discuss a larger observational attempt to leverage Bones as a high-resolution tracer of Galactic structure in concert with 3D dust extinction mapping and a new uniform catalog of Giant Molecular Clouds. Finally, we discuss how much of this work is made possible by the development of a new visualization software package, Glue, which enables unprecedented 3D volume rendering of the Milky Wayś molecular gas and dust.