Oral Presentation Abstracts
Monday, September 21, 2009

Jonathan Tan (University of Florida)

General Theory of Star Formation

Star formation theories require close guidance from observations and numerical experiments. I review recent theoretical and observational progress in our understanding of how star formation proceeds. With the aim of understanding galactic scale star formation rates, I start with what we are learning from detailed studies of Galactic star-forming regions. Individual stars appear to form from gas cores that have a mass spectrum comparable to the stellar initial mass function. Star formation is highly clustered within turbulent giant molecular clouds. Studies of mid-infrared dark clouds are revealing important information about the earliest phases of star cluster formation. I discuss the timescale of star cluster formation and review the evidence that it is long compared to the free-fall time of the natal gas clump. In this case, the gas clump can be considered to be globally in near virial and pressure equilibrium, with turbulence driven internally by protostellar outflows. Returning to the earliest phases of star cluster formation, I consider the physical mechanisms that may initiate the process, including compressions induced by ISM turbulence, GMC collisions and stellar feedback. I compare predictions of these theories for the radial profiles of SFRs in disk galaxies with observed systems. I conclude by discussing how these theories extend into the starburst regime.

Frank Bigiel (UC Berkeley)

A.Leroy (MPIA)
F. Walter (MPIA)
E. Brinks (University of Hertfordshire)
E. de Blok (University of Cape Town)
B. Madore (Carnegie Observatories)

The Star Formation Law on sub-kpc Scales - From the Inner Disks to the Outskirts of Nearby Galaxies

I will present results from THINGS ('The HI Nearby Galaxy Survey') and HERACLES ('HERA CO Line Extragalactic Survey') on the relation between gas and star formation (SF) in a sample of 18 nearby galaxies. These results include a detailed pixel-by-pixel study of the star formation (Schmidt/Kennicutt) law on 750 pc resolution, using THINGS HI, HERACLES CO, Spitzer 24 μm and GALEX FUV data. This is the first time that the scaling relation between gas and SF has been measured at high resolution across the entire star forming disks of a large sample of nearby galaxies, spirals and dwarfs, in a systematic way. I will show that a Schmidt law with power law index $N = 1.0 \pm 0.2$ relates star formation surface density and molecular gas surface density in the star forming disks and that the star formation efficiency (SFE), i.e. the SFR rate per unit total gas mass, and the ratio of H_2 to HI are both strong functions of radius and thus environment in a galaxy. I will compare these results to those of a new study, comparing SF to gas in the extreme environments of outer galaxy disks (out to twice the optical radius r_{25}) in a sample of 25 nearby galaxies. At around the edge of the star forming disk, there is a strong spatial correlation between HI and FUV emission, which becomes weaker with increasing radius. On average, the outer disk HI exponential scalelengths are twice as large as the FUV scalelengths. The SFE (here SFR normalized to HI mass) in this regime is a strong function of both HI column and radius and implies HI depletion time scales of many Hubble times.

Jarle Brinchmann (Leiden Observatory)

Moving past the Kennicutt-Schmidt relation - gas-star formation scaling laws for 200,000 galaxies in the SDSS

The estimation of gas content in galaxies without radio/mm observations has long been dominated by the Kennicutt-Schmidt relationship which, while very useful, are merely scaling relationships and not measurements. Here we present a novel method of estimating total gas content from optical emission lines. We show that the technique gives very good results when compared to radio/mm estimates of gas content, with an accuracy comparable to that achieved in radio/mm studies.

We then apply this to the SDSS DR7 and derive gas content distribution functions and the star-formation - gas content relation for 200,000 galaxies spanning a wide range in physical properties. We study the $\mu_{gas} - \mu_{SFR}$ and gas mass/SFR vs stellar mass density relationships and show that both relationships depend on further parameters. We show in particular that the star formation efficiency, gas mass/SFR, is a clear function of metallicity. We end by pointing out the weaknesses and advantages of this technique for future studies, in particular the synergy with ALMA studies of galaxies.

Mark Krumholz (UC Santa Cruz)

Star Formation Laws for Atomic and Molecular Gas

I discuss a simple theoretical model for star formation in which the local star formation rate in a galaxy is determined by three factors. First, the interplay between the interstellar radiation field and molecular self-shielding determines what fraction of the gas is in molecular form and thus eligible to form stars. Second, internal feedback determines the properties of the molecular clouds that form, which are nearly independent of galaxy properties until the galactic ISM pressure becomes comparable to the internal GMC pressure. Above this limit, galactic ISM pressure determines molecular gas properties. Third, the turbulence driven by feedback processes in GMCs makes star formation slow, allowing a small fraction of the gas to be converted to stars per free-fall time within the molecular clouds. Combining analytic estimates for each of these leads to a single star formation law, which can be formulated in terms of either the atomic or molecular content of a galaxy, and agrees very well with observations to date. I discuss how this model can be tested and extended using the capabilities of ALMA and other future observatories.

Bruce Elmegreen (IBM T.J. Watson Research Center)

Initial Mass Functions

A review of the stellar IMF will be presented, including recent ideas for changing IMFs in different locations and times. Protostellar clump mass functions will also be reviewed, with an assessment of their connection to the stellar IMF. Simulations and theories which reproduce the IMF will be discussed. ALMA will likely be the IMF instrument we have all been waiting for. It should be able to observe the last and densest phases of star formation in local regions, where the IMF is established, and through measurements of velocities, densities, ionization fractions and molecular abundances, determine the dominant processes for stellar assembly.

Chris Hayward (Harvard-Smithsonian Center for Astrophysics)

Kai Noeske (Harvard-Smithsonian Center for Astrophysics)
Stijn Wuyts (Harvard-Smithsonian Center for Astrophysics)
Patrik Jonsson (UC Santa Cruz)
T.J. Cox (Harvard-Smithsonian Center for Astrophysics)
Desika Narayanan (Harvard-Smithsonian Center for Astrophysics)
Lars Hernquist (CfA)

Calibrating and Testing Star-Formation Rate Indicators Using Simulations

We analyze N-body/smoothed-particle hydrodynamics simulations of isolated and merging galaxies, performed using *Gadget-2* (Springel 2005), with the 3-D adaptive grid, polychromatic Monte Carlo radiative transfer code *Sunrise* (Jonsson, Groves, and Cox 2009, Jonsson 2006). We apply commonly used UV, optical, and IR star-formation rate (SFR) indicators to the spectral energy distributions of the simulated galaxies in order to determine how well the SFR indicators recover the known SFR in the simulations. The models upon which the SFR indicator calibrations are based must necessarily make simple assumptions about physical properties of the galaxies, e.g., the star formation history (SFH), whereas all such properties in the simulations are known and are closer to those of actual galaxies. This benefit of the simulations enables us to test and compare SFR indicators in a way that is complimentary to observational studies. We use our approach to provide more sophisticated calibrations of the SFR indicators and to characterize systematic errors and uncertainties caused by SFH, dust and source geometry, viewing angle, contamination from active galactic nuclei and old stellar populations, and assumed initial mass function, stellar population synthesis model, and dust model. We focus on how well the SFR indicators, which are primarily tested observationally for local galaxies, apply to simulations of high-redshift galaxies.

Matt Malkan (UCLA)

Far-IR Spectral Diagnostics of Starbursts and AGN

Far-IR spectroscopy with ISO has shown us how to separate out the energy produced by young stars from that produced by accretion onto a central massive black hole. Some of the key diagnostic lines, of [O I], [O III], and [C II] carry significant fractions of the total energy output, and thus can be detected by ALMA in galaxies with sufficiently high redshifts. The greatest scientific yield comes from ALMA observations at the highest frequencies. Some specific examples will be presented.

Alberto Bolatto (University of Maryland)

Molecular Gas at Low Metallicities: what we know and what ALMA will tell us

Prevalent in the primitive universe, environments poor in heavy elements are common today in the form of dwarf galaxies or the outer disks of large spirals. Particularly prominent examples are the Magellanic Clouds, with abundances 1/2 and 1/5 Solar, or the extreme local dwarfs IZw18 and SBS 0335-052 with abundances $\sim 1/35$ Solar. In this talk I will discuss how the lack of heavy elements shapes the molecular interstellar medium and the star formation in these objects, how the local metal-poor systems illuminate our understanding of the high-redshift universe, and what role ALMA will play at studying the physics of these environments at low and high redshifts.

Janice Lee (Carnegie Observatories)

Armando Gil de Paz (Departmento de Astrofisica, Universidad Complutense de Madrid)
Christy Tremonti (Department of Astronomy, University of Wisconsin)
Robert Kennicutt, Jr. (Institute of Astronomy, University of Cambridge)
Samir Salim (NOAO)

Measuring Star Formation Rates in Dwarf Galaxies

I will share recent results on the measurement of star formation rates (SFRs) which involve the (mis-)behavior of low-luminosity systems relative to expectations based on our more developed understanding of normal star-forming spiral galaxies.

Using a complete, statistical sample of star-forming galaxies within the Local Volume, we evaluate the consistency between SFRs inferred from Hα nebular emission and the far ultraviolet non-ionizing continuum. Our analysis probes activities ranging from those that are characteristic of the Milky Way to ultra low SFRs of 10^{-4} M$_\odot$ yr^{-1}. We securely establish that there is a systematic decline of the integrated Hα-to-FUV flux ratio as galaxies less active than the Small Magellanic Cloud are probed. Thus, if standard linear SFR conversion recipes are applied, the UV yields a higher SFR than Hα, by factors of two to more than 10, in this regime. It has been argued that such a systematic may be evidence for a non-universal stellar initial mass function. We discuss this and other possible causes of the observed discrepancy.

Stacy McGaugh (University of Maryland)

Ji Hoon Kim (Seoul National University)

Star Formation in Gas Rich Low Surface Brightness Galaxies

The gas mass fraction of spiral galaxies is correlated with both luminosity and surface brightness. For the dimmest galaxies, it is not uncommon for the gas to outweigh the stars, and gas fractions can exceed 90% in the most extreme cases. Using Hα as a star formation tracer, we find that while the absolute star formation rates are low (< 0.1 M$_\odot$/yr), the stellar birthrates are typically high (b > 2). It is not clear what the star formation history of these galaxies is, nor how star formation proceeds at all in these extreme environments which, being low metallicity and gas rich, may be our best local analogs to conditions at high redshift. To date, essentially all of the observed gas is in the atomic phase; how much molecular gas is present, and how it comes and goes, is an open question begging for future facilities such as ALMA.

Karen O'Neil (NRAO-GB)

Gas and Star Formation in Massive Low Surface Brightness Galaxies

Massive low surface brightness galaxies have disk central surface brightnesses at least one magnitude fainter than the night sky, but total magnitudes and masses that show they are among the largest galaxies known. Like all low surface brightness (LSB) galaxies, massive LSB galaxies are often in the midst of star formation yet their stellar light has remained diffuse, raising the question of how star formation is proceeding within these systems. HI observations have played a crucial role in studying LSB galaxies as they are typically extremely gas rich. In the past few years we have more than quadrupled the total number of massive LSB galaxies, primarily through HI surveys. To clarify their structural parameters and stellar and gas content, we have undertaken a multi-wavelength study of these enigmatic systems. The results of this study, which includes HI, CO, optical, near UV, and far UV images of the galaxies, combined with recent simulations on the formation of massive LSB galaxies, will provide the most in depth study done to date of how, when, and where star formation proceeds within this unique subset of the galaxy population.

Martha Haynes (Cornell University)

The ALFALFA Team

The HI Census from the ALFALFA Survey

The Arecibo Legacy Fast ALFA (ALFALFA) survey is an on-going blind HI survey designed to obtain a census of HI-bearing objects over a cosmologically significant volume of the local universe. To date, about 72% of the ALFALFA observations have been completed, and the current working catalog contains some 10500 high quality detections extracted from about 1700 square degrees of sky. ALFALFA is specifically designed to detect gas rich low mass halos nearby and to probe the HI mass functions in different environments, including voids, nearby groups such as Leo, and the Virgo cluster. ALFALFA provides measures of the HI gas mass and disk rotational velocity for thousands of objects in common with SDSS, 2MASS, GALEX etc, permitting a global view of gas content and its relationship to structural properties, stellar and dynamical mass estimators, star formation and AGN indicators, and to their dependence on local environment. Here I will present an overview of recent ALFALFA results.

Timothy Heckman (Johns Hopkins University)

The GALEX Arecibo SDSS Survey (GASS)

The GALEX Arecibo SDSS Survey (GASS) is designed to measure the HI properties of 1000 galaxies with SDSS spectra and optical images and GALEX ultraviolet images. These galaxies are selected to fairly sample the entire galaxy population over the range of stellar mass between 10^{10} and $10^{11.5}$ solar masses over the redshift range 0.025 to 0.05 and down to a limit of $M_{HI}/M_* = 1.5\%$. I will present preliminary results based on the first 250 galaxies, and also summarize results from a pilot program with IRAM to measure the molecular gas. We find strong scaling relations between the HI content and both the stellar population and structural properties of the galaxies. We find candidates for recent accretion events (very high HI mass fractions in otherwise normal red and dead early type galaxies) as well as candidates for on-going quenching of star formation (galaxies with significant recent star formation but little or no HI). The implications for our understanding of galaxy evolution will be briefly summarized.

Amanda Kepley (UVa)

Kelsey Johnson (UVa/NRAO)
Remy Indebetouw (UVa/NRAO)
Crystal Brogan (NRAO)

Star Formation in Nearby Galaxies with ALMA

The Atacama Large Millimeter/submillimeter Array (ALMA), currently under construction in Chile, will allow us to probe star formation in nearby galaxies with a level of detail and sensitivity previously reserved for the Milky Way and the Magellanic Clouds. Here we use observations of star-forming regions in our Galaxy and the Magellanic Clouds to predict what ALMA will be able to see in star forming regions in nearby galaxies and guide future observations with this remarkable instrument.

Jessica Krick (Spitzer Science Center)

Carrie Bridge (Spitzer Science Center)
Eric Murphy (California Institute of Technology)
Vandana Desai (Spitzer Science Center)
James Neill (California Institute of Technology)

The First UV Intracluster Plume in the Virgo Cluster

We are conducting a multi-wavelength project to explore the intracluster light (ICL) in the Virgo cluster as a record of the interaction history and evolution of galaxies in clusters. We have discovered the first ever ICL feature in the UV with *GALEX*. This feature is ~ 50 kpc long, ~ 40 kpc from the interacting galaxy pair NGC4438/4435, and is spatially coincident with an ICL plume detected in the deep V–band imaging of Mihos et al. (2005). The presence of this feature in the UV is extremely surprising because previous optical analyses indicate that intracluster stars are old, and should therefore be undetected in the UV. Spectral energy distribution (SED) fitting of the *GALEX* and optical data of this plume reveal not only a population of young intracluster stars but also the first substantial evidence for significant amounts of intracluster dust. We have recently been awarded deep *Spitzer* Warm IRAC 3.6 and 4.5 μm data and have proposed for deeper *GALEX* FUV and NUV imaging over the central square degree of the Virgo cluster. The complete dataset from UV to IR will allow us to explore the SED of the ICL in unprecedented detail to constrain the origin of the ICL and understand the so far unexplained high metallicity of the intracluster medium. The intracluster features we have already discovered, and those we are likely to discover with coming data are good targets for follow-up observations with ALMA and EVLA to understand what the gas is doing in relation to the stars and dust which will inform models on the origin of the intracluster light and the formation of galaxy clusters.

Daniel Dale (University of Wyoming)

The Wyoming Survey for Hα

The *Wyoming Survey for Hα* is a large-area, ground-based, narrowband imaging survey for distant Hα-emitting galaxies. The survey spans several square degrees in a set of fields of low Galactic cirrus emission and covers multiple cosmic epochs. Probing down to luminosities far below the knee of the luminosity function at each epoch will allow a robust determination of the evolution in the Hα luminosity function and thus the cosmic star formation rate density. Initial results are presented here for several hundred galaxies observed out to a redshift of $z \sim 0.4$, and ongoing collaborative efforts in the near-infrared are extending this survey out to $z \sim 2.2$. There is a mild but clear evolution with lookback time in the volume-averaged cosmic star formation rate.

Lisa Young (New Mexico Tech)

Martin Bureau (University of Oxford)
Timothy Davis (University of Oxford)
Katherine Alatalo (UC Berkeley)
Leo Blitz (UC Berkeley)
Atlas3D team (various)

Molecular Gas and the Evolution of Early-Type Galaxies

The Atlas3D project is probing the assembly history and star formation history of a complete volume-limited sample of 263 nearby early-type (elliptical and lenticular) galaxies. These issues are addressed with full two-dimensional maps of the stellar kinematics, age and metallicity, and ionized gas in all the targets, plus HI imaging, a CO survey, follow-up interferometric CO imaging, and ancillary data at other wavelengths. Here we focus on the molecular gas results. CO emission is detected in 23% (+/- 3%) of this sample, even though the sample is not biased towards possible star formation indicators. Low-level star formation activity is usually taking place in the molecular gas and it can be detected in the stellar populations, ionized gas line ratios, IR and radio continuum emission. Molecular gas is present in virialized Virgo Cluster members at nearly the same rate as in non-members, indicating that it is difficult to remove the molecular gas from a galaxy even after several Gyr of residence in the cluster potential. The interferometric CO imaging reveals that at least half of the field (non-Virgo-Cluster) early-type galaxies acquired their molecular gas recently from an external source (accretion, interaction, or a merger), but the same is not true for the Virgo Cluster members. We speculate on the role of gas and dissipational processes in the transition from the blue cloud to the red sequence.

Alison Crocker (University of Oxford)

Martin Bureau (University of Oxford)
Lisa Young (New Mexico Tech)
Francoise Combes (Observatoire de Paris LERMA)
Melanie Krips (IRAM Grenoble)

Molecular gas and star formation in early-type galaxies

Elliptical and lenticular galaxies have long been thought to be 'red and dead' stellar systems without ongoing star formation or cold gas. Varied observations now firmly indicate that this is not true - E/S0s have both cold gas (HI, H_2, dust) and recent star formation (detected in UV, absorption linestrengths and ionized emission lines). However, little is yet known about the details of star formation in these galaxies. Having obtained both molecular gas maps (using mm interferometers) and optical integral field unit (IFU) data that give spatially resolved information on the stellar populations, stellar kinematics and ionised gas, we are now at a stage where the process of star formation in E/S0 galaxies may be studied. We find ionised gas always present where there is molecular gas (with shared kinematics), however star formation is surprisingly not always the cause of this ionisation. Moreover, while most E/S0s with molecular gas host young stellar populations, about a third do not according to both absorption linestrength analysis and UV-optical colours. Based on all these observations, a very tentative evolutionary sequence can be made, with pre-star formation, star-forming and dwindling-star formation categories. Comparing the E/S0s with molecular gas to the star-forming correlations between the FIR, radio and $H\beta$ emission, we find that the E/S0s are $H\beta$ deficient and FIR-strong. Despite this FIR-strength, the FIR is well correlated with the mass of molecular gas detected and we find that using the standard FIR-SFR conversion, our galaxies are consistent with both a constant star formation efficiency and/or a Schmidt-Kennicutt law. Further investigations into the physical conditions of the molecular gas in E/S0s are underway with observations in HCN, 13CO and HCO^+. Preliminary results show different 13CO/12CO and HCN/HCO^+ ratios than observed in spiral, starburst or Seyfert galaxies, indicating a difference in the state or chemistry of the molecular gas.

Oral Presentation Abstracts
Tuesday, September 22, 2009

Jin Koda (Stony Brook University)

CARMA Nobeyama CO survey of nearby galaxies

I plan to present results from the CARMA and Nobeyama CO survey of nearby galaxies, including the distribution of giant molecular clouds, clouds with and without star formation, and cloud lifetime.

Adam Leroy (MPIA (Heidelberg))

Fabian Walter (MPIA)
Frank Bigiel (UC Berkeley)
The HERACLES and THINGS Teams

Testing Drivers of Cloud and Star Formation in Nearby Galaxies

I will present the latest results from our IRAM CO survey (HERACLES) and our VLA HI survey (THINGS), on what drives star and cloud formation in nearby galaxies. We make local measurements of the H_2-to-HI ratio and the gas depletion time (the gas surface density divided by the star formation rate) and compare these to proposed drivers of star and cloud formation. The combination of HERACLES, THINGS, SINGS, and the GALEX NGA mean that for the first time it is possible to make these measurements in a systematic way across the entire disk of many (40) galaxies. I will focus on the impact of metallicity, the interstellar radiation field, spiral density waves, ISM pressure, and large-scale instabilities on the local H2/HI ratio and the gas depletion time, all quantities that have been predicted to affect the conversion of HI into H_2 or the ability of gas to form stars. We find the transition from HI to H_2 to be the strongest driver of the gas depletion time, with the H2/HI ratio itself more clearly related to local ISM properties than large-scale instabilities.

Kazushi Sakamoto (ASIAA)

Molecular Gas and Dust in ULIRGs : SMA view

Ultraluminous Infrared Galaxies (ULIRGs) are merging galaxies with extremely vigorous starburst or quasar-class AGNs. Local ULIRGs may be $z \sim 0$ analogs of the merging events that many galaxies experienced during their assembly process. If so, we can study in local ULIRGs the interplay of gas content, star formation, and AGN activities in detail in the important period when galaxies rapidly evolve. I am going to review recent observations of molecular gas and dust in ULIRGs made using the Submillimeter Array (SMA). The submillimeter-capability and high-resolution of the SMA give us a glimpse of how the ALMA will transform our understanding of ULIRGs.

Jeremy Darling (University of Colorado)

Kyle Willett (University of Colorado)

Lessons About Star Formation and Merging from Molecules and Dust

We present recent advances in our understanding of gas physics, star formation, and merging in galaxies based on multi-wavelength diagnostic studies of molecules and dust. In particular, we focus on the most extreme merger-induced starbursts and identify physical conditions that distinguish these from lesser starbursts. Non-thermal molecular tracers are particularly revealing, including OH megamaser emission and formaldehyde absorption of cosmic microwave background photons. We present a new understanding of the root causes of OH megamaser emission (and thus what OH megamasers physically indicate in major mergers), including Spitzer-derived dust properties. We suggest that these new insights can provide predictions for subsequent galaxy and black hole evolution and for the timing and duration of extreme starbursts. Finally, we look forward to ALMA-EVLA applications of these diagnostics at higher redshifts, spanning the history of cosmic star formation.

Susanne Aalto (Chalmers University of Technology, Sweden)

Francesco Costagliola (Chalmers University of Technology, Sweden)

IR and mm tracers of starburst evolution - HC$_3$N in obscured galaxies

I will present some initial results of our mm/submm study of chemical tracers of evolution in starbursts and AGNs. I will focus on HNC and HC$_3$N and what we can learn about unusual physical and chemical conditions in deeply obscured galaxies. I will present the first detection of an HNC maser - and the extreme excitation of HC$_3$N in NGC4418. The intense IR radiation field strongly impact also the mm/submm transitions of these species.

Satoki Matsushita (ASIAA)

CO View of Molecular Gas around AGNs

We performed interferometric multi-transition CO observations toward several nearby galaxies with active galactic nuclei (AGN). At a large scale (100 pc scale), our sample galaxies show linear velocity gradient near the AGN, suggesting the existences of molecular gas disks or tori rotating around the AGN. On small scales (10 pc), however, the molecular gas distribution and kinematics do not always keep the features that are seen on large scales; some show very disturbed features, some show small scale rotating features. In this talk, we will show the distribution, kinematics, and physical conditions of molecular gas around the AGN, and discuss relations between molecular gas and star formation or AGN activities.

DongChan Kim (University of Virginia)

Sylvain Veilleux (University of Virginia)
David Rupke (University of Hawaii)

Mid-IR Diagnostics of Star Formation in QUEST Sample

The Quasar/ULIRGs Evolution Study (QUEST) is a comprehensive program designed to study the evolutionary connection between ultraluminous infrared galaxies (ULIRGs) and quasar hosts. This program combines optical and near-infrared imaging and spectroscopic data obtained from the ground and from the space with the Hubble Space Telescope (H-band imaging) and Spitzer Space Telescope (IRS spectroscopy). Here, we report a summary of mid-IR diagnostics of star formation in 74 ULIRGs and 34 Palomar Green (PG) quasars. Six independent methods have been applied to quantify starburst fraction to the bolometric luminosity in these systems. On average, a starburst contribution in ULIRGs is ∼60%, ranging from ∼75% among cool ($f_{25}/f_{60} < 0.2$) optically classified HII-like and LINER ULIRGs to ∼50% and ∼25% among warm Seyfert 2 and Seyfert 1 ULIRGs, respectively. This number decreases ∼20% in PG QSOs. We find a morphological trend along the strong, modest, and weak starburst-dominated ULIRGs to the PG QSO sequence, in general agreement with the standard ULIRG to QSO evolutionary scenario.

Andreea Petric (Spitzer Science Center /Caltech)

L. Armus (SSC/Caltech)
J. Howell (SSC/Caltech)
J. Mazzarella (SSC/Caltech)
A. Evans (UVA)
J. Surace (SSC/Caltech)

MIR Diagnostics and Warm Molecular Gas in Local Luminous Infrared Galaxies in the GOALS Sample

We present spectra taken with the Infrared Spectrograph on Spitzer covering 5-38 μm region of 248 nuclei of luminous infrared galaxies (LIRGs) found as part of the Great Observatories All-sky LIRG Survey (GOALS) to isolate the AGN versus starburst contribution to the MIR emission and the fate of molecular warm and cold gas along a merger sequence of LIRGs. The high ionization lines [NeV] and [OIV] suggest that only 2% of LIRGs are AGN dominated. The EQWs of the 6.2 PAH feature indicate that 16% of sources are AGN dominated. Diagnostics based on the shape of the MIR continuum imply that 19% of the sources have a hot dust component which may be associated with an AGN. No obvious correlations are found between the AGN contribution to the IR and the merger stage or luminosity of these galaxies in contrast to what is found in ULIRGs. The 6.2 PAH EQW are used to estimate an AGN contribution of 14% to the IR power in those sources. We use observations of the pure rotational transitions of molecular hydrogen S(0) (28.22 μm), S(1) (17.04 μm) , S(2) (12.28 μm) and S(3) (9.67 μm) to determine the mass and temperature of the warm gas. We detect the H_2 S(0), S(2) and S(3) transitions in about 30-40% or all sources and S1 in 94% of our objects. We find a wide range of ratios of the H_2 to the IR luminosities between $\sim 7 \times 10^{-5}$ and 1.7×10^{-3} with a median of 2×10^{-4}. We find a weak correlation between the warm H_2 mass and IR luminosity. The derived H_2 temperatures seem to change with merger stage in that more advance mergers appear to have higher temperatures. We compare the results obtained for the GOALS galaxies to similar studies of nearby galaxies and ULIRGs.

Todd Thompson (The Ohio State University)

Maximal Starbursts: Theory & Reality

Radiation pressure from the absorption and scattering of starlight by dust grains may be the dominant feedback mechanism in starburst galaxies. I describe the conditions for which star formation in galaxies is effectively Eddington-limited and self-regulated. In this picture, starbursts may be thought of in analogy with individual radiation pressure supported massive stars. I present evidence for this picture on the galaxy scale, on the scale of individual star clusters, and on parsec scales around active galactic nuclei, by comparing directly with observations of extreme star-forming environments at low and high redshift.

Julio Navarro (University of Victoria)

Numerical Simulations of Hierarchical Galaxy Formation

I will briefly review the status, successes, and main shortcomings of current numerical simulations of galaxy formation, with particular emphasis on the ability of simulations to form realistic galaxy morphologies and to account for the observed abundance/properties of satellite galaxies. I will also discuss ongoing efforts to simulate the formation and evolution of the Milky Way galaxy in its proper cosmological setting.

Alyson Brooks (Caltech)

The Role of Cold Flows in the Early Growth of Galaxies

Using high resolution cosmological hydrodynamical simulations and comparisons to semi-analytic models, I will demonstrate that cold gas accretion, particularly along filaments, modifies the standard picture of shocked gas accretion and cooling onto galaxy disks. Even when a hot halo is able to develop in more massive galaxies, there exist dense filaments that penetrate inside of the virial radius and deliver cold gas to the central galaxy, leading to star formation at higher redshifts than predicted by the standard model. For galaxies up to $\sim L^*$, cold accretion gas is responsible for the star formation in the disk at all times to the present. In concert with supernovae feedback, star formation in the disk is regulated, leading to the development of a cold gas reservoir that helps to quickly reform disks despite disruption in major mergers.

Carrie Bridge (Caltech)

Ray Carlberg (University of Toronto)
Mark Sullivan (University of Oxford)

Evolution in the Merger Rate: Implications for Mass Assembly, Star Formation and AGN Activity

Using the Canada France Hawaii Telescope Legacy Survey (CFHTLS-Deep) we have developed a new physically-driven classification system to identify major galaxy-galaxy mergers based on the presence of tidal tails and bridges. These morphological features are robust signatures of recent or ongoing merger activity. This technique was applied to 2 sq. degrees (30,000 galaxies) of the (CFHTLS-Deep) and complied into the CFHTLS-Deep Catalog of Interacting Galaxies. The survey's depth, high image quality and Spitzer coverage have made it possible to probe the merger rate, and level of induced star formation and AGN activity throughout the merger sequence to $z \sim 1$. I will present our following key findings: 1) strong evidence for an evolving merger rate, 2) mass assembly downsizing 3) star formation and AGN triggering in mergers and 4) a larger merger fraction in Luminous IR galaxies.

Jennifer Lotz (NOAO)

The Effect of Gas on Observations of the Galaxy Merger Rate

Gas-rich mergers are more easily identified by their disturbed morphologies than mergers with less gas. Because gas-rich galaxies and mergers are expected to be more common at high redshift, the under-counting of gas-poor mergers may bias current estimates of the evolution of galaxy merger rate. To understand the magnitude of this bias, we explore the effect of gas fraction on the optical morphologies of simulated disk galaxy mergers. We determine how the timescales for identifying galaxy mergers via quantitative morphology depend on baryonic gas fraction f_{gas}. Strong asymmetries last significantly longer in high gas-fraction mergers, with timescales ranging from ≤ 300 Myr for $f_{gas} \sim 20\%$ to ≥ 1 Gyr for $f_{gas} \sim 50\%$. Therefore the strong evolution observed in the fraction of asymmetric galaxies may reflect a strong evolution in the gas properties of merging galaxies rather than the global galaxy merger rate. On the other hand, the timescale for identifying a galaxy merger via double nuclei is not a strong function of f_{gas}, consistent with the weak evolution observed for $G - M_{20}$ merger candidates. In the coming decade, ALMA will be crucial for measuring the evolution of gas-rich mergers and their contribution to galaxy assembly.

Shardha Jogee (University of Texas at Austin)

T. Weinzirl (University of Texas at Austin), S. Miller (University of Oxford)
K. Penner (University of Arizona, Steward Observatory), R. E. Skelton (Max-Planck-Institut für Astronomie), C. J. Conselice (The University of Nottingham), R. S. Somerville (Max-Planck-Institut für Astronomie)
E. F. Bell (Max-Planck-Institut für Astronomie), X. Z. Zheng (Purple Mountain Observatory)
H-W. Rix (Max-Planck-Institut für Astronomie), A. R. Robaina (Max-Planck-Institut für Astronomie)
F. D. Barazza (Laboratoire d'Astrophysique, École Polytechnique Fédérale de Lausanne)
M. Barden (Institute for Astro- and Particle Physics, University of Innsbruck)
A. Borch (Max-Planck-Institut für Astronomie), S. V. Beckwith (Johns Hopkins University)
J. A. Caldwell (University of Texas, McDonald Observatory)
C. Y. Peng (NRC Herzberg Institute of Astrophysics), C. Heymans (SUPA, Institute for Astronomy, University of Edinburgh)
D. H. McIntosh (University of Massachusetts)
B. Häußler (The University of Nottingham), K. Jahnke (Max-Planck-Institut für Astronomie)
K. Meisenheimer (Max-Planck-Institut für Astronomie)
S. F. Sanchez (Centro Astronmico Hispano Alemn), L. Wisotzki (Astrophysikalisches Institut Potsdam), C. Wolf (University of Oxford), C. Papovich (Texas A&M University)

Galaxy Mergers and their Impact on Star Formation over the last 10 Gyr

Mergers, smooth accretion, and secular processes are relevant for the assembly and central activity of galaxies in hierarchical models of galaxy evolution, but their relative importance at different epochs remains hotly debated. I will discuss evidence that major mergers play a less important role in driving galaxy evolution since $z \sim 2$ than previously thought, based on two of our published studies: Jogee et al. and the GEMS collaboration 2009 (J09) and Weinzirl et al.(2009; W09). In W09, constraints on the merger history over the last 10 Gyr are presented based on the structural property of local bulges. In J09, we explore the frequency of galaxy mergers and their impact on star formation over the last 7 Gyr, based on 3700 intermediate mass ($M \geq 1 \times 10^9$ $M_\odot$) from the GEMS survey, with HST ACS, COMBO-17, and Spitzer data. Our results are: **(1)** Among high mass galaxies, we find a modest (major+minor) merger fraction of below 10% out to a redshift of $z \sim 0.80$, over the last 7 Gyr. For a visibility timescale of 0.5 Gyr, we estimate that over $z \sim 0.24$–0.80 (lookback of 3–7 Gyr), $\sim 68\%$ of high mass systems have undergone a merger of mass ratio $> 1/10$, with 16%, 45%, and 7% of these corresponding respectively to major, minor, and ambiguous mergers. **(2)** We compare the empirical merger history for high mass galaxies to theoretical predictions from ΛCDM-based halo occupation distribution models, semi-analytic models, and hydrodynamic SPH simulations. We find qualitative agreement between observations and models such that the (major+minor) merger fraction or rate from different models bracket the observations, and show a factor of five dispersion. Near-future improvements can now start to rule out certain merger scenarios. **(3)** Among both intermediate and high mass systems, we find that the mean SFR of visibly merging systems is only modestly enhanced compared to non-interacting galaxies, such that visibly merging systems only account for less than 30% of the cosmic SFR density over this interval. Thus, the decline in the cosmic SFR density over the last 7 Gyr is predominantly shaped by non-interacting galaxies. Future facilities like ALMA will be instrumental in exploring this issue further.

Kristen Shapiro (University of California, Berkeley)

The SINS team

SINFONI Integral-Field Observations of Massive Star-Forming Galaxies at z~2

I will present recent results from the SINS integral-field survey of star-forming galaxies at z~2. Our on-going program has revealed evidence for a substantial population of large, rotating disks fueled by cold accretion of gas. The resulting high gas fractions of these systems create super-HII regions, which play an important role in the evolution of these massive galaxies at z~2 and their transformation into their present-day form. Other gas processes, including galactic winds and AGN, are also observed and are likely critical to the understanding of the early evolution of these galaxies.

Maurilio Pannella (NRAO)

C. L. Carilli (NRAO)
E. Daddi (CEA - Paris)
F. N. Owen (NRAO)
A. Renzini (INAF - Padova)
V. Strazzullo (NRAO)

Star formation and dust obscuration at $z \approx 2$: galaxies at the dawn of downsizing

I present first results of a study aimed to constrain the star formation rate and dust content of galaxies at z≈2. I use a sample of BzK-selected star-forming galaxies, drawn from the COSMOS survey, to perform a stacking analysis of their 1.4 GHz radio continuum as a function of different stellar population properties, after removing AGN contaminants from the sample. Dust unbiased star formation rates are derived from radio fluxes assuming the local radio-IR correlation. The main results of this work are: i) specific star formation rates are constant over about 1 dex in stellar mass and up to the highest stellar mass probed; ii) the dust attenuation is a strong function of galaxy stellar mass with more massive galaxies being more obscured than lower mass objects; iii) a single value of the UV extinction applied to all galaxies would lead to grossly underestimate the SFR in massive galaxies; iv) correcting the observed UV luminosities for dust attenuation based on the Calzetti recipe provide results in very good agreement with the radio derived ones; v) the mean specific star formation rate of our sample steadily decreases by a factor of ~ 4 with decreasing redshift from $z = 2.3$ to 1.4 and a factor of ~ 40 down the local Universe.

These empirical SFRs would cause galaxies to dramatically overgrow in mass if maintained all the way to low redshifts, we suggest that this does not happen because star formation is progressively quenched, likely starting from the most massive galaxies.

Jason Melbourne (California Institute of Technology)

Lee Armus (Spitzer Space Telescope)
B. T. Soifer (Caltech)
V. Desai (Spitzer Space Telescope)

Near-IR Spectroscopy Reveals Buried AGN Within z=2 Dust Obscured Galaxies (DOGs)

Spitzer mid-IR imaging has revealed a class of extremely Dust Obscured Galaxies (DOGs) with a redshift distribution centered about $z = 2$. Defined by very red optical to IR colors, $f_{24\mu m}/f_R > 1000$ (e.g. redder than Arp 220 at every redshift), DOGs are extreme even for ultra-luminous infrared galaxies. With clustering strengths similar to low redshift massive ellipticals, DOGs may represent an early, formative stage of the most massive galaxies in the universe. Optical-to-IR spectral energy distributions (SEDs) and mid-IR spectroscopy suggest two classes. DOGs with power-law SEDs show strong silicate features in their mid-IR spectra, typical of AGN activity. DOGs with a mid-IR "bump" in their SEDs exhibit strong PAH features in mid-IR spectroscopy, suggesting star formation. We recently obtained Palomar Triplespec near-IR spectroscopy of both power-law and "bump" DOGs. The power-law DOGs show very broad $H\alpha$ lines ($FWHM > 1000$ km/s) redshifted into the near-IR bands, further proof of a strong AGN power source. The "bump" DOGs however, show much narrower $H\alpha$ ($FWHM \sim 300$ km s^{-1}). Integral field spectroscopy obtained with OSIRIS and the Keck laser guide star adaptive optics system, shows that $H\alpha$ flux in the power-law DOGs is extremely concentrated with little to no emission arising from a more extended narrow-line region. This may indicate that star formation has already begun to shut down in the AGN dominated DOGs.

Vandana Desai (Caltech; Spitzer Science Center)

Arjun Dey (NOAO)
Emeric Le Flo'ch (Institute for Astronomy, University of Hawaii)
B. T. Soifer (Caltech/Spitzer Science Center)
Emma Cohen (Caltech)

The Dirt on Dry Mergers

Dry merging (i.e., merging without gas) is invoked in models of hierarchical galaxy formation as an important mode of galaxy assembly, necessary to reproduce the observed fractions and luminosities of galaxies in the red sequence. In one prominent study, van Dokkum (2005), hereafter vD05, found that 70% of nearby ($z \sim 0.1$) optically red early-type galaxies show signs of tidal interaction, and concluded that the majority of luminous field ellipticals were formed via dry mergers. We present the long wavelength Spitzer/MIPS (3.6-70 μm) SEDs of the vD05 sample. We find that a significant fraction of the dry mergers identified by vD05 are found to have mid-IR emission in excess of what would be expected from a passively evolving galaxy. Based on mid-IR colors, dusty star formation is the likely source of this mid-IR excess. The derived SFRs are large for passive galaxies, with $\approx$25% of the dry merger candidates exhibiting SFRs > 1 $M_\odot$ yr^{-1}. We will discuss the implications of these results for the relevance of dry merging in the formation of early-type galaxies, as well as the potential impact of ALMA observations on dry merger scenarios.

Gregory Snyder (Harvard-Smithsonian Center for Astrophysics)

TJ Cox (Harvard-Smithsonian Center for Astrophysics)
Chris Hayward (Harvard-Smithsonian Center for Astrophysics)
Lars Hernquist (Harvard-Smithsonian Center for Astrophysics)
Desika Narayanan (Harvard-Smithsonian Center for Astrophysics)

Poststarburst Galaxies in Merger Simulations

Poststarburst (or "E+A") galaxies, defined by a recently truncated burst of star formation as determined from optical spectral lines, are prime testing grounds for the merger hypothesis. Local E+A galaxies are most likely objects transforming from gas-rich disks to passively evolving, early-type galaxies as the result of galaxy interactions. In addition, since we expect it to appear shortly after the bright AGN phase in major mergers, the poststarburst phase offers a unique opportunity to study the post-merger effects of quasar and star formation feedback on the remaining gas reservoir. We present our efforts to model E+A galaxies using fully three-dimensional numerical simulations of galaxy mergers. We find that merging gas-rich disks of nearly equal mass on a variety of orbits can produce the optical features of a poststarburst galaxy. We discuss whether galaxy mergers can account for the population of E+As found in spectroscopic surveys. We compare our poststarburst models to observations in various wavelength regimes in an attempt to understand the properties of any remaining gas and its star-formation history. Specifically, we test whether our models can produce the E+A signature while highly obscured star formation continues. We describe what our models say about the poststarburst phenomenon at higher redshifts, and consider how JWST might be used to select $z > 1$ counterparts to nearby E+A galaxies. We assess the role of ALMA and the EVLA in detecting and characterizing the remaining gas content, and Herschel for determining the importance of dust-enshrouded star formation. We highlight how such observations might be used to advance our knowledge of the relationship between mergers, star formation, and galaxy evolution.

Dennis Zaritsky (University of Arizona)

Implications and Applications of the Fundamental Manifold

How many parameters are necessary to describe galactic structure? What is the connection of those parameters to physically meaningful quantities? I will describe our methodology for determining the dimensionality of galactic structure and demonstrate that all stellar systems form a nearly a 2-dimensional manifold in a 3-dimensional parameter space. This construct contains the well-known special cases (Tully-Fisher and Fundamental Plane) but has the distinct advantage of describing galaxies of all luminosities and morphological type with a single relationship. I will then discuss extensions of this formalism to constrain the star formation efficiency of galaxies, the range of baryon concentrations, and test stellar population models.

Oral Presentation Abstracts
Wednesday, September 23, 2009

Dominik Riechers (Caltech)

Gas Dynamics and Massive Galaxy Assembly Back to <1 Billion Years after the Big Bang

Detailed studies of the molecular gas content and dynamics in the highest redshift AGN host galaxies are vital for our understanding of the formation and evolution of massive galaxies. Molecular gas is the prerequisite material for star formation to occur. Also, gas dynamics can be used to trace the gravitational potential of galaxies, and thus, to obtain an independent estimate of the total mass in their central few kiloparsecs. This technique thus provides the possibility to set an upper limit on the gas fraction and stellar content of AGN host galaxies out to the earliest cosmic times, where direct observations of stellar light are not possible due to the brilliance of the AGN at optical/infrared wavelengths. Measuring the gas fraction is important to determine the evolutionary state of a galaxy, and to constrain gas depletion timescales and starburst lifetimes. Determining the stellar mass of distant galaxies is important to investigate whether or not the (in the nearby universe) linear relation between stellar mass and black hole mass in early-type galaxies evolves with cosmic time and/or toward the high mass end. Here, I present the results of a dynamical, high resolution (0.15 arcsec, or 1 kpc at $z >4$) study of molecular gas in quasar host galaxies out to z=6.4 (i.e., within 1 Gyr of the Big Bang) with the Very Large Array (VLA), which we performed to address these questions. These observations set the pace for future investigations of star formation and galaxy assembly out to the first galaxies that form in the universe, which will facilitate the capabilities of the upcoming Expanded Very Large Array (EVLA) and the Atacama Large (sub-)Millimeter Array (ALMA).

Andrew Harris (Department of Astronomy, University of Maryland)

A.J. Baker (Rutgers University)
C.E. Sharon (Rutgers University)
A.M. Swinbank (Durham University)
I. Smail (Durham University)
The Cosmic Eyelash Team

The molecular ISM of high-redshift galaxies

Recent developments have expanded the number of molecular lines available to explore the molecular interstellar medium in galaxies at high redshifts. The additional information provides new constraints on the physical state of the molecular gas, a tracer of the material associated with star formation.

Here we present Zpectrometer/GBT observations of the rest-frame 3 mm waveband from a number of galaxies in the redshift range $z = 2$ to 3. The Zpectrometer is an ultra-wideband spectrometer built specifically to search for and characterize low-excitation transitions in high-redshift galaxies. Observations of low-excitation lines provide surprisingly strong constraints on the warm ISM as well as the cool components.

As part of discussing the multi-phase ISM revealed by the Zpectrometer, we also present associated new molecular line results from the GBT, PdBI, 30 m, and SMA telescopes on the brightest submillimeter galaxy known, the "Cosmic Eyelash."

Our approach includes a critical treatment of the constraints modeling can provide given a range of lines at different energies and systematic errors. While some high-redshift galaxies seem to have interstellar media that can be characterized by single-component models, something that is not observed in local galaxies, new data are beginning to reveal more complex conditions within high-redshift nuclei. The results are a foretaste of the results that ALMA, the EVLA, and the GBT will harvest in coming years.

Jeff Wagg (ESO/NRAO)

Nissim Kanekar (NRAO)
Chris Carilli (NRAO)

The molecular gas content of $z >$6.5 Lyman Alpha emitters

Little is known about the gas content of "normal" galaxies at redshifts, $z >$6.5, around the time the Universe is believed to have been reionized. Dust, along with atomic and molecular gas have been detected in extremely luminous quasars at these early epochs, however, measuring the gas and dust content of less-luminous galaxies, such as Lyman-alpha emitters, has proven challenging. I will present GBT observations of CO line emission in two $z >$6.5 lyman alpha emitters, with the goal of measuring their molecular gas content. One of these, HCM6A at z=6.56, has been amplified by gravitational lensing, so that we are able to place strong constraints on its molecular gas content. I will also present observations of thermal dust continuum emission and the 158μm C+ line emission in HCM6A using the PdBI.

Lin Yan (Caltech)

Nicolas Fiolet (IAP)
L. Tacconi (MPE)
A. Sajina (Caltech)
A. Omont (IAP)
P. Cox (IRAM)

Detection of Cold Molecular Gas in Spitzer Selected $z \sim 2$ ULIRGs

I will present CO interferometric observations of 9 $z \sim 2$ ULIRGs using PdBI. The CO observations are in low-medium spatial resolution. The targets are bright in 24μm with flux density greater than 1 mJy, and initially discovered by the mid-IR spectroscopy. Eight of the 9 sources show significant CO detections, with integrated CO luminosities of (1-5)x10^7 $L_\odot$, and cold molecular gas of (1.3-3.8)x$10^{10} M_\odot$. Of the 8 detections, four sources show double peak CO line profiles. The CO velocity width of the 8 sources range from (150-300) km s^{-1}, similar to that of QSOs, much smaller than the averaged value of SMGs. With analysis combining all of the available data from spectroscopy in optical, mid-IR and CO, and multi-wavelength photometry, we compare these bright 24μm $z \sim 2$ ULIRGs with SMGs and high-z, CO emitting QSOs. I will show what we learn about the history of the black hole growth and stellar assembly of these Spitzer ULIRGs, and discuss the implication to the understanding of galaxy and black hole co-evolution.

Robert Bussmann (University of Arizona)

Arjun Dey (National Optical Astronomy Observatory)

Comparing the specific star formation rates of $z \sim 2$ ULIRGs: DOGs and SMGs

The advent of the *Spitzer* Space Telescope has revolutionized the field of IR astronomy by resolving most of the Cosmic IR background. Comprising a significant component of the IR background is a new population of $z \sim 2$ ULIRGs which has been identified via the combination of deep IR imaging with *Spitzer* and ground-based imaging in the optical (Dust Obscured Galaxies, or DOGs). In this contribution, we undertake a systematic comparison of the intrinsic properties of DOGs and sub-millimeter galaxies (SMGs), another well-studied $z \sim 2$ ULIRG population. We utilize far-IR + radio imaging to estimate star formation rates and mid-IR + optical data to estimate stellar masses and thereby obtain specific star formation rates.

Jason Prochaska (UC Santa Cruz/UCO)

On the (Non)Evolution of HI Gas in Galaxies

I will discuss constraints on the nature of HI gas in galaxies at z=0 to z=5 from 21cm and Lya observations. In turn, I will present a "swimming pool model" of galaxy formation based on inferences from these HI observations.

Kotaro Kohno (University of Tokyo)

AzTEC-on-ASTE survey of dusty extreme starburst galaxies

In order to unveil the hidden part of the cosmic star formation, we have conducted unprecedentedly wide and deep $\lambda\,1100\,\mu$m imaging surveys of dusty extreme starburst galaxies or submillimeter-bright galaxies (SMGs) using the bolometer camera AzTEC mounted on the submillimeter-wave telescope ASTE in Northern Chile. The total coverage of the survey area exceeds a few deg^2 with a typical noise level (1 σ) of 0.5 - 1.0 mJy at $\lambda\,1100\,\mu$m (or roughly equivalent to 1 - 2 mJy at $\lambda\,850\,\mu$m), that is deep enough to uncover ULIRG-class dusty violent starbursts lying $z > 1$. Major blank fields, such as Subaru XMM-Newton Deep Field (SXDF), Subaru Deep Field (SDF), AKARI Deep Field South (ADF-S), GOODS-S, and COSMOS, have been extensively observed, and ~ 40 over density regions traced by high-z radio galaxies and clusters of optically selected galaxies such as LAEs and LABs have also been mapped. In this presentation, the emphasis will be placed on (1) the on-going efforts to investigate the multi-wavelengths properties of the newly detected SMGs mainly in SXDF, SDF, and ADF-S, and (2) a plan to explore the energy sources of them using our newly developed diagnostic method, based on high angular resolution, high sensitivity mm/submm molecular spectroscopy accomplished by ALMA.

Min Yun (University of Massachusetts, Amherst)

The AzTEC/ASTE Team

Nature of the Sources Identified by the AzTEC 1100 μm Surveys

During the last three years, we have surveyed over 3 sq. degree of the "blank" and biased regions of the sky using the AzTEC 1100 μm camera on the JCMT and the ASTE telescopes, detecting over 1000 sources. As already discussed by our recent papers on the analysis of their number counts and spatial distribution, we found intriguing evidence for significant cosmic variance and possible association with large scale structure for these so-called "submillimeter galaxy" population. In this talk, I will discuss the properties of individual AzTEC sources derived from the complementary multi-wavelength data and the significance of the AzTEC selected galaxy population in the context of the overall galaxy evolution and mass build-up history.

Joaquin Vieira (University of Chicago / KICP)

John Carlstrom (University of Chicago / KICP)
Daniel Marrone (KICP / NRAO)

A new sample of (sub)mm galaxies discovered with the South Pole Telescope

The South Pole Telescope (SPT) is a 10m telescope currently surveying hundreds of square degrees in the southern sky down to mJy RMS levels at 1.4, 2, and 3 mm. The SPT is optimized for fine-scale temperature anisotropy measurements of the cosmic microwave background (CMB) and the primary science goal is a mass limited survey of clusters of galaxies via the Sunyaev-Zeldovich effect (SZE). I will discuss the first and latest results from this project, with an emphasis on a new sample of (sub)mm extragalactic sources we have discovered. These objects are rare and extremely bright sub-mm galaxies (SMGs). I will present evidence that these objects are strongly lensed and at higher mean redshift than typical SMGs.

Thomas Greve (MPIA)

Axel Weiss (MPIfR)
Fabian Walter (MPIA)
Ian Smail (Durham)
Kristen Coppin (Durham)

A LABOCA survey of the ECDFS: the submillimeter properties of near-infrared selected galaxies

The 330hr ESO-MPG 870 μm survey of the Extended Chandra Deep Field South (ECDFS) obtained with the Large Apex BOlometer CAmera (LABOCA) on the Atacama Pathfinder EXperiment (APEX), was used to carry out a stacking analysis at 870 μm of a sample of 8266 $K_{vega} \leq 20$ selected galaxies from the Multi-wavelength Survey by Yale-Chile (MUSYC). Subsamples of 744 starforming BzK galaxies (sBzKs), 1253 extremely red objects (EROs) and 737 distant red galaxies (DRGs) all have significant stacked submm signals. A delineation of the average submm signal from $K_{vega} \leq 20$ selected galaxies as a function of (photometric) redshift, and find a decline in the average submm signal (and therefore IR luminosity and star formation rate) by a factor $\sim 2 - 3$ from $z \sim 2$ to $z \sim 0$. This is in line with a cosmic star formation history in which the star formation activity in galaxies increases significantly at $z > 1$. By mapping the stacked 870 μm signal across the $B - z$ vs. $z - K$ diagram we have confirmed the ability of the sBzK-selection criterion to select starforming galaxies at $z > 1.5$.

Alexandra Pope (NOAO)

Ranga-Ram Chary (SSC/Caltech)

New observational constraints on the sources of the cosmic infrared background

We present new observational constraints on the sources of the cosmic infrared background (CIB) from 70-500 μm. We perform a careful stacking analysis to determine the contribution of mid-IR (Spitzer/MIPS) selected galaxies to the background. Our stacking analysis is backed by detailed simulations which predict the fraction of the background resolved by a given population. We find that half of the CIB is still unresolved at submillimeter wavelengths - this fraction of the background must therefore be coming from luminous infrared galaxies (LIRGs) or sub-LIRGs at $z > 1$. We discuss the implications of this on the cosmic star formation rate density. Future extragalactic surveys with Herschel will get closer to resolving all the background but it will not be until ALMA that we are able to individually detect LIRGs at $z > 1$ in the submillimeter and thus provide a complete census of the redshift and luminosity distribution of the sources of the CIB.

Desika Narayanan (Harvard-Smithsonian Center for Astrophysics)

Christopher C. Hayward (Harvard University)
Thomas J. Cox (CfA/OCIW)
Lars Hernquist (Harvard University)
Philip Hopkins (UC Berkeley)
Joshua D. Younger (Harvard/IAS)

The Infrared Zoo at $z \sim 2$

Redshift $z \sim 2$ is perhaps the richest epoch for understanding galaxy assembly. During this era, the bulk of the Universal stellar mass was assembled, and the cosmic SFR density and black hole growth both peak. While it is clear that Infrared-selected galaxies at $z \sim 2$ appear to be a key player in both forming copious numbers of stars, and growing black holes, the myriad of infrared selection techniques ranging from 24 μm to 1 mm has uncovered a veritable zoo of galaxies (e.g. Dust Obscured Galaxies [DOGs], Submillimeter Galaxies [SMGs], and 1-mm galaxies) whose relationship to one another is unclear. Utilizing a novel combination of high resolution hydrodynamic simulations of galaxy evolution, 3D polychromatic dust radiative transfer calculations and 3D non-LTE molecular line radiative transfer simulations, we will synthesize the plethora of species in this infrared zoo, and provide a merger-driven unifying model connecting DOGs, SMGs, and 1mm selected galaxies. We will discuss the dominant power source as galaxies evolve through their various phases, and assess their relative contributions to both cosmic stellar mass assembly and supermassive black hole growth. If time permits, we will discuss how these galaxies relate to the optically-selected BzK galaxies, and imminently feasible tests of these models with the LMT and/or the IRAM 30m.

Ranga-Ram Chary (SSC/Caltech)

The Growth of Galaxies and the Role of Dust at 2< z <8.3

I will present recent results on the evolution of the ultraviolet luminosity function of galaxies over the first gigayear of the Universe. Although, it is clear that dust was produced early in the Universe, I will assess the importance of dust extinction on measured star-formation rate densities at z >2. I will demonstrate that although rare dusty galaxies may be present, the average extinction among z >2 galaxies, appears to be lower than that inferred from the ultraviolet slope. Finally, I will present tentative evidence for the evolution of dust grain size distribution with redshift and its implications for future surveys.

Alison Peck (ALMA/NRAO)

on behalf of the combined Antenna Integration, Commissioning and Operations teams (ALMA)

The Current Status of ALMA

The Atacama Large Millimeter/Submillimeter Array (ALMA) is an international millimeter/submillimeter interferometer under construction in the Atacama Desert of northern Chile. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of Japan by the National Astronomical Observatory of Japan (NAOJ) and on behalf of North America by the National Radio Astronomy Observatory (NRAO). ALMA is situated on a high-altitude site at 5000m elevation which provides excellent atmospheric transmission over most of the wavelength range of 0.3 to 3 mm. At the shortest planned wavelength and most extended configuration, the angular resolution of ALMA will be 5 milliarcseconds. This will give us the ability to, for example, image the gas kinematics in protostars and in protoplanetary disks around young Sun-like stars at a distance of 150 pc, or to image the redshifted dust continuum emission from evolving galaxies at epochs of formation as early as z = 10.

At present, there are 18 scientists from all over the world working at the Joint ALMA Observatory in Santiago, all of whom are assisting with commissioning and planning activities, as well as carrying out their own research programs. A number of antennas have been delivered and assembled by the vendors at the Operations Support Facility (OSF) at 3000m near San Pedro de Atacama. The first three antennas have been conditionally accepted by ALMA, and are in the process of being assessed by our engineering and science staff in Chile. We expect to be doing interferometric tests using a single baseline correlator during 2009, so that extensive evaluation of the full system can be done at the OSF. These antennas will then be moved to the high site at the end of the year and commissioning will begin with fringes and phase closure using the full ALMA correlator shortly after that. The call for proposals for Early Science observations is planned in late 2010, with full science operations in 2012.

Philip Appleton (NASA Herschel Science Center: Caltech)

Michelle Cluver (IPAC, Caltech)
Patrick Ogle (SSC, Caltech)
Francois Boulanger (IAS, Orsay)
Pierre Guillard (IAS, Orsay)

Galaxy Spectroscopy From Spitzer to Herschel: Mapping the Dominant IR Cooling Channels in Shocked Gas

I will review recent Spitzer IRS Observations which are revealing a population of galaxies which emit a substantial amount of their luminosity through rotational Mid-IR H_2 lines, dominating line emission from star formation by a large factor. Starting with the giant shock in Stephans Quintet, which represents the first group-wide discovery of powerful H_2 emission in the absence of star formation, I will discuss the Ogle-sample of 3CR radio galaxies. These galaxies share some of the same H_2 emitting properties as Stephans Quintet, but we believe feedback effects of radio jets are the prime driver of the strong cooling lines. My talk will also cover the spectroscopic opportunities available to astronomers with Herschel, and how these observations, which have strong synergy with ALMA, can help to fill-in a missing and essential set of far-IR cooling channels. This legacy will feed into future far-IR missions and have implications for shocked gas at high redshift.

David Frayer (IPAC)

FIDEL Team (NOAO, IPAC, SSC, CEA)
S-COSMOS Team (IfA, IPAC, SSC, CIT, CEA)

Deep Far-Infrared Surveys with Spitzer and Expectations for Herschel

We will discuss the results from the deep 70+160 μm surveys with Spitzer of the GOODS-N, FIDEL, and COSMOS fields. The counts, confusion level, evolution of the infrared luminosity function, the radio-to-infrared correlation, and the variation of galaxy SEDs will be discussed. The Spitzer surveys show significant numbers of infrared-cool high-luminosity sources which highlights the importance that Herschel will have in measuring the far-infrared/sub-mm SEDs of galaxies at high redshift.

Andrew Blain (Caltech)

The Herschel multi-tiered Extragalactic Survey (HerMES): ALMA Synergies

The ESA-led Herschel mission was launched on May 14th 2009. Herschel will study this emission from 70 to 600 μm, spanning the peak of this cosmic infrared background. In addition, information concerning the Japanese Akari all-sky survey is becoming available and NASA's Wide-Field Infrared Survey Explorer (WISE) is scheduled to launch on 7th December.

Herschel is extremely complementary to ALMA. While both probe obscured emission, ALMA provides much higher resolution, sensitivity and powerful spectral diagnostics while Herschel samples the peak of the spectral energy distributions of galaxies, has no concerns about atmospheric windows and provides a much higher mapping speed. Several large legacy programs have been approved for Herschel.

The guaranteed-time Herschel multi-tiered Extragalactic Survey (HerMES) aims to characterize the bolometric emission from obscured galaxies and map this star-formation history both temporally and spatially. HerMES is the largest Herschel project, involving 900 hours or 5mission. It will map over 70 square degrees including most famous deep extragalactic survey fields. HerMES will detect over 100,000 such galaxies (building on the few 100 sub-mm galaxies found using ground-based telescopes today), and will provide an invaluable legacy for studies of galaxy evolution at all wavelengths.

I will place the HerMES in the context of existing and future multi- wavelength surveys, and In focus on the power of the WISE and Herschel surveys to provide target samples for ALMA.

Pierre Cox (IRAM)

Recent Results and Future Plans at IRAM: the NOEMA project

Tom Oosterloo (Netherlands Institute for Radio Astronomy)

All-sky radio surveys with the WSRT

I will describe Apertif, the upgrade to the Westerbork Synthesis Radio Telescope (WSRT) with focal plane arrays. With Apertif, the survey speed of the WSRT will increase by a factor 30. All-sky spectroscopic surveys (HI and OH) as well as continuum/polarisation surveys will be performed with Apertif. Several hundred thousand galaxies will be detected and imaged in HI, out to $z = 0.4$. With these data, the evolution of gas content, and the role it plays in the evolution of galaxies, can be studied.

I will describe the system and show the results from a prototype focal plane array mounted in the WSRT. I will also describe the surveys plans for Apertif.

Brian Mason (NRAO)

S.R. Dicker (U.Penn)
M.J. Devlin (U.Penn)
P. Korngut (U.Penn)
J. Aguirre (U.Penn)
D. Benford (NASA/GSFC)

MUSTANG, a 3mm bolometer array for the GBT

The Multiplexed SQUID TES Array for Ninety Gigahertz (MUSTANG) is a 90 GHz bolometer camera built for use as a facility instrument on the 100-meter Robert C. Byrd Green Bank Telescope (GBT). MUSTANG comprises an 8 by 8 focal plane of transition edge superconductor bolometers read out using time-domain multiplexed SQUID electronics. It operates at the Gregorian focus of the GBT in a rotating turret housing seven other receivers. Initial engineering observations took place in late 2006 and substantial improvements to the instrument have since been made. Two open calls for shared-risk proposals have been made in 2008; for the June 1, 2009, MUSTANG was available for general use on the GBT and it will be available in future proposal calls. In the near future we aim to install a larger, lower-noise detector array in MUSTANG. Since the multiplexing electronics have substantial unused capacity, this detector array could readily have 4 times as many pixels as the current array and would require minimal ancillary changes to the receiver. MUSTANG is a pathfinder for a large-format bolometer array on the GBT. Having successfully dealt with the major risks such an instrument would face we are now making plans for its construction. We present an overview of the instrument, some early science results, and our development plans for the future.

Eric Murphy (Caltech)

The Far-Infrared–Radio Correlation at High-z: From ALMA to the SKA

Using improved estimates for the IR luminosities of 24 μm detected sources in GOODS-North, where deep 70 μm data have been taken as part of the FIDEL survey, we search for, and do not find, significant evidence for evolution in the FIR-radio correlation out to $z \sim 2$. While evolution in the FIR/radio ratios with redshift is not observed, we expect the FIR-radio correlation to deviate as the importance of cosmic-ray electron cooling from Inverse Compton (IC) scattering off of the CMB, whose energy density goes as $U_{\mathrm{CMB}} \sim (1 + z)^4$, becomes increasingly important relative to synchrotron cooling by a galaxy's internal magnetic field. To combat IC losses off of the CMB at $z \gtrsim 3$, magnetic field strengths need to reach values in excess of $\gtrsim 50$ μG. The existence of strong magnetic fields in galaxies at such early epochs relative to the field strengths in galaxies today is unexpected; magnetic fields are thought to build up over time and not decay quickly. However, a strong (84 μG) field has recently been detected at $z \approx 0.7$, and radio quiet QSOs at $z \sim 6$ appear to lie on the canonical FIR-radio relationship.

After deriving a realistic sensitivity goal for the SKA, we show how the combination of these deep radio continuum surveys with data from future FIR/submm/mm facilities such as *Herschel*, ALMA, CCAT, SPICA, and eventually CALSITO/SAFIR, will help characterize the star-forming, AGN, and magnetic field properties of IR bright ($L_{\mathrm{IR}} \gtrsim 10^{11}$ $L_{\odot}$; SFR $\gtrsim 25$ $M_{\odot}$ yr^{-1}) galaxies at all redshifts. Furthermore, by taking advantage of the fact that the non-thermal component of a galaxy's radio continuum emission will be quickly suppressed by IC losses off of the CMB, leaving only the thermal (free-free) component, we argue that deep radio continuum surveys at frequencies larger than $\gtrsim 10$ GHz may prove to be the best probe for characterizing the star formation history of the Universe.

James Condon (NRAO, CV)

The Role of the EVLA and SKA in the ALMA Era

How can these very different telescopes best work together to study star-forming galaxies? Continuum diagnostics of the star-formation rate include synchrotron radiation at low frequencies, free-free emission dominating near 100 GHz, and thermal dust emission at higher frequencies. The EVLA will complement ALMA with comparable sensitivity and angular resolution at frequencies up to 50 GHz, mitigating the lamented loss of ALMA Band 1 for observing free-free emission from HII regions, high-opacity dusty accretion disks, and very large grains. The EVLA will also cover ground-state lines of heavy molecules plus cool CO at all redshifts $z > 1.4$. The very sensitive (especially for surveys) SKA will detect synchrotron emission and exploit the FIR/radio correlation to measure the evolution of star-formation rates in normal galaxies at modest redshifts, and possibly in luminous high-redshift galaxies, where free-free emission is a faint but reliable indicator at the 10 GHz upper frequency limit of the SKA. However, usable sensitivity of the SKA may be limited by dynamic range, and the low-frequency K-correction is unfavorable for discovering the first starburst galaxies.

Oral Presentation Abstracts
Thursday, September 24, 2009

Christy Tremonti (MPIA)

Starburst and AGN Feedback

The influence of massive stars and accreting black holes on the surrounding interstellar medium, termed 'feedback', has been regarded as an important ingredient of galaxy evolution since the 1970's. Feedback of some form is included in nearly all modern numerical simulations, but our understanding of the complex interplay between the baryonic constituents of galaxies is still woefully incomplete. Some of the best empirical constraints on the feedback process come from the study of its most dramatic manifestation: galactic-scale gaseous outflows or galactic winds. I will review observational and theoretical progress in the study of galactic winds and highlight opportunities and challenges for the coming decade.

Zhi-Yun Li (UVa)

Peng Wang (Stanford)
Tom Abel (Stanford)
Fumitaka Nakamura (Niigata University, Japan)

Outflow Feedback-Regulated Massive Star Formation

I will present a new theory of massive star formation in turbulent cluster-forming dense clumps of molecular clouds. In this theory, the massive star formation is fed by the material from the parsec-scale clump rather than a core, and is regulated by the protostellar outflows driven from both low mass and high mass stars. I will illustrate the basic properties of this theory with high-resolution, ENZO-based, AMR MHD simulations that include sink particles and outflow feedback. Implications of the theory for the galaxy formation simulations and ALMA observations will be discussed.

Michael Fall (STScI)

Formation and Disruption of Star Clusters

This talk presents some new results regarding the formation of star clusters in dense molecular clouds and their subsequent disruption by a variety of processes. These processes are essential steps in the formation of stellar populations. Most if not all stars form in clusters and most if not all clusters are eventually destroyed, releasing their members stars into the surrounding stellar field. Some of these processes operate in much the same way in the star clusters of all galaxies. We discuss observational evidence for such regularities and likely theoretical explanations.

Mark Lacy (NRAO/NAASC)

Andreea Petric (Spitzer Science Center, Caltech)
Susan Ridgway (NOAO)
Anna Sajina (Haverford College)
Tanya Urrutia (Spitzer Science Center)
Duncan Farrah (Sussex)

Dust obscured radio-quiet quasars at high redshifts

The currently popular paradigm of massive galaxy and black hole co-evolution, in which galaxy mergers trigger both starbursts and quasar activity at high redshifts, predicts a large fraction of dust obscured quasars at $z \gtrsim 2$. Candidates for such objects can be found relatively easily using mid-infrared selection from Spitzer surveys, but obtaining redshifts (and hence space densities, luminosities and other physical parameters) is much more challenging, given the faintness of these objects in the optical and near-infrared. We will present our progress to date towards obtaining a large sample of dust obscured, radio-quiet high redshift quasars, preliminary results from which indicate that dust obscured objects are likely to dominate the co-moving space density of luminous quasars at $z \gtrsim 2.5$. We will also present early follow-up work in the far-infrared and submm which suggests that many of these objects are indeed associated with highly luminous starbursts, and discuss how ALMA and EVLA can be used to help us understand the nature of these objects and their relation to the normal quasar population.

Nick Scoville (Caltech)

Large Scale Structure and Galaxy Evolution

Extensive observations at $z < 3$ have clearly demonstrated the most significant role played by large scale structure environment in speeding the formation of the first galaxies. I will describe these key data from the COSMOS survey showing both the evolution of large scale structures and environmentally correlated galaxy evolution and then review strategic opportunities for observing the first galaxies with ALMA and JWST.

Jeyhan Kartaltepe (University of Hawaii)

Multiwavelength Properties of 70 μm Selected Galaxies in the COSMOS Field

We present the results of a multiwavelength study of a complete sample of 1507 70 μm selected galaxies in the COSMOS field. We have obtained an accurate measure of the total infrared luminosity by fitting various template libraries to the mid to far infrared spectral energy distribution and discuss the variations in the full SED shape from the ultraviolet to the far infrared. We identify potential AGN using several different methods and find that the fraction of 70 μm sources that host powerful AGN increases strongly with L_{IR}. The morphological properties of these sources indicate that the fraction of major mergers also increases with luminosity while the fraction of spirals drops. Their U-V colors show that they reside in the "green valley" in between the blue cloud of star forming galaxies and the red sequence of quiescent ellipticals suggesting that they represent a significant transition population.

Manuel Aravena (NRAO)

Chris Carilli (NRAO)
Frank Bertoldi (Argelander Institut fuer Astronomie)
Eva Schinnerer (Max-Planck Institut fuer Astronomie)
Peter Capak (Caltech)

The Environment of Submillimeter Galaxies

Submillimeter galaxies (SMBs) are luminous and massive systems undergoing vigorous star formation activity. Their large masses, number density and clustering properties indicate that they are related to the formation of structures at high redshift, and possibly they may the precursors of luminous local ellipticals. In this talk, I will present a study of the environment of the SMGs detected with MAMBO in the COSMOS field and with LABOCA in the ECDF-S. Using density maps of low- and high-redshift BzK galaxies we investigate whether some of the brightest SMGs are located in galaxy overdensities. A few SMGs in these surveys appear to be linked to significant overdensities of star-forming galaxies at $z > 1$. Such overdensities are compact in size, similar to what is found in QSO fields at similar redshifts. We use accurate optical/IR photometric redshifts to give an estimate of the actual redshift of these associations. Using the angular cross-correlation function between SMGs and BzK galaxies at high-redshift we find that there is a close relationship between both populations in scales $< 10''$. Such compact groups could trigger the extreme star-forming activity seen in some SMGs and they represent good targets for studies of star and structure formation in normal to starburst galaxies in the crucial epoch of galaxy assembly.

Sara Ellison (University of Victoria)

The galaxy mass-metallicity relation and its dependence on environment

Environment affects many aspects of a galaxy's evolution. In this talk, I will present results on the dependence of the galaxy mass-metallicity relation on local (presence of a close companion), intermediate (nearest neighbours) and large scale (cluster membership) environment.

Brian Kent (NRAO)

Galaxy Environment and the HI structure of the Virgo Cluster

Large HI surveys are cataloging the neutral gas content of nearby galaxies. In particular, the wide-field Arecibo Legacy Fast ALFA survey (ALFALFA, Giovanelli et al. 2007, Kent et al. 2008) is making use of the 21 cm line of neutral hydrogen to measure the properties of some 30,000 galaxies in the local Universe. The survey samples a variety of galaxy environments, including the nearby Virgo Cluster at 16.7 Mpc. The HI data complements existing databases with information on the luminous stellar and molecular content of the various morphological populations in the cluster. I will discuss the HI content of the galaxies in the cluster, as well as the HI mass function for the sample of member galaxies.

Philip Hopkins (UC Berkeley)

The Role of Gas in the Formation of Disks and Bulges: More Important than You Think

In the last few years, the combination of models that include realistic large gas supplies in galaxies, and prescriptions for feedback from both stellar evolution and super-massive BHs to maintain those gas reservoirs, have led to huge shifts in our understanding of galaxy formation and may represent the solution to many outstanding problems in galaxy formation. In particular, gas-richness may represent the most important driving factor in the effects of galaxy-galaxy mergers. The degree of gas-richness in mergers has dramatic effects on bulge structural properties, stellar populations, mass profiles, and kinematics; models with the appropriate gas content have finally begun to produce realistic bulges that resolve a number of discrepancies and make unique predictions that allow for new observational probes of bulge merger histories. In the regime of very gas-rich mergers, expected at high redshift and/or low masses, gas can qualitatively change the character of mergers, making disks robust to destruction in mergers and providing a natural explanation for the observed morphology-mass relation. Ignoring the effects of gas in changing the dynamics of galaxy assembly has order-of-magnitude consequences for observed galaxy demographics.

Kartik Sheth (Caltech / NRAO)

Debra Elmegreen (Vassar College)
Bruce Elmegreen (IBM)
Jason Melbourne (Caltech)
Susan Kassin (Oxford University)
Ben Weiner (Steward Observatory, U. Arizona)

Dependence of Galactic Structure on the Dynamical State of Galaxies

How does the formation of galactic structure depend on the dynamic state of the disk? We have addressed this question using kinematic data from the DEEP2 survey and accompanying HST imaging data from the AEGIS survey in a sample of galaxies between $0.2 < z < 0.84$. We find that the dispersion-dominated systems, where $\sigma > v_{rot}$, are either compact (< 5 kpc) systems, or are clump-cluster/chain galaxies. The latter are believed to be proto-galaxies caught in the act of building their disks via vigorous bursts of star formation. In contrast, the rotation-dominated systems ($v_{rot} > 30$ km/s $>> \sigma$) are more "normal" disks with bars and spiral arms. As in the local Universe, not all rotationally dominated disks have bars suggesting that the cold dynamic state of the disk is a necessary but not a sufficient condition for the formation of bars. We also find three examples of clump-cluster/proto-bar systems which show bar-like structures in dynamically hot, i.e. dispersion dominated galaxies - the nature of these galaxies is not fully understood.

Our study is a prelude to the detailed dynamical analysis of galaxies that will be possible with gas observations using ALMA and the eVLA over the time of galaxy formation and evolution. JWST will be provide observations of the underlying stellar content in galaxies over cosmic time. Together these facilities will be cornerstones to trace the assembly and evolution of galaxies.

Grant Wilson (University of Massachusetts)

The AzTEC/ASTE team

Triggered Star Formation in Cluster Environments

We have used the AzTEC mm-wavelength camera to make deep (1 mJy rms) and large (15 arcminute diameter) maps of 43 known clusters and proto-clusters spanning $0 < z < 6$. This survey, called the AzTEC/ASTE Cluster Environment Survey, or ACES, is the largest of its kind and represents a rich data set for the study of the stellar mass buildup in extreme starbursting systems in mass-biased environments over a broad range of cosmic time. Observations are complete and analysis is ongoing. Here I will report on initial results which focus on the relationship between the starbursting galaxy population and mass biased regions of our universe.

Jeremy Lim (University of Hong Kong)

Cool Molecular Gas in Central Cluster Giant Elliptical Galaxies

I briefly review the properties and possible origins of cool molecular gas (as detected in CO) in the central cD (giant elliptical) galaxies of rich clusters in the Local Universe. About 20 such galaxies have now been detected, exhibiting molecular gas masses in the range 10^9-10^{11} $M_\odot$. This is much larger than the molecular gas masses commonly found in low-z field ellipticals, which seldom exceed $\sim 10^9$ $M_\odot$ and never $\sim 10^{10}$ $M_\odot$. Also, unlike field ellipticals which usually show a double-horned CO line profile indicative of rotating disks as has been confirmed in all cases well mapped, the CO line profile of central cD galaxies do not show a preferred pattern. All the central cD galaxies detected in molecular gas lie in clusters with strong putative X-ray cooling flows. So far, only one has been well mapped in molecular gas, that of NGC 1275 in the Perseus Cluster. I show that the properties of the molecular gas in this galaxy is consistent with radial free-fall, arguing against cannibalisms (as is believed to be the case in many field ellipticals) but suggesting instead an origin from a X-ray cooling flow.

Poster Presentation Abstracts

Elizabeth Adams (Cornell University)

Riccardo Giovanelli (Cornell University)
Martha P. Haynes (Cornell University)
Amelie Saintonge (Institute for Theoretical Physics, University of Zurich)

Identification and Detection of Compact High Velocity Clouds in the ALFALFA Survey

For over two decades now, the mismatch between the number of low mass halos predicted by dark matter simulations and the number of observed low mass galaxies has been recognized (e.g. Klypin et al. 1999). Much work has gone into resolving this discrepancy, both in finding missing low mass galaxies and explaining why low mass halos may not host luminous galaxies. Recently, a class of compact high velocity clouds (CHVCs) have been detected in the ALFALFA survey that are consistent with the interpretation that they are minihalos in the Local Group. A preliminary sample of these objects, identified manually, are described in Giovanelli et al. (2009, in prep). These objects do not violate ΛCDM halo scaling parameters and are of low enough mass ($\sim 10^5 \, d^2_{Mpc} \, M_\odot$) that they would not have been detected by HI surveys of nearby galaxy groups other than the Local Group. Here, we present preliminary results from a signal extraction method designed to automatically detect these objects in data from the ALFALFA survey.

Kate Barnes (Indiana University)

Liese van Zee (Indiana University)
Evan D. Skillman (University of Minnesota)

UV Colors of Star Forming Regions in the Outer Disks of Spiral Galaxies: the Effects of an Episodic Star Formation History

We have obtained deep FUV, NUV, and Hα imaging of a small sample of nearby spiral galaxies in order to study the recent massive star formation in the outer disk. We have identified $\sim$20-60 individual star forming regions outside of R_{25} for most of the galaxies in our sample. Similar to other studies, the UV colors of star forming regions in the outer disks show a large amount of scatter. We are able to reproduce the observed range of FUV-NUV colors using GALAXEV models with episodic sampling of exponentially declining star formation rates. We compare results for both the inner and outer disk; we find that the time between star formation episodes combined with the ratio of current to past star formation rate has a pronounced effect on the predicted range of FUV-NUV color. An episodic star formation history could occur if star formation in the outer disk is largely a stochastic phenomenon, or if it is self-regulated by stellar winds or SNe.

Sandipan Basu (Florida International University)

Trisha Ashley (Florida International University)
Caroline E. Simpson (Florida International University)
Deidre A. Hunter (Lowell Observatory)
The LITTLE THINGS team

The LITTLE THINGS Survey

The processes that lead to star formation on galactic scales are poorly understood even in the simplest systems in the universe, dwarf galaxies. At best we have incomplete knowledge of certain processes in certain environments. Here we present preliminary HI images of a small subset of galaxies from the LITTLE THINGS Survey: a complete dataset on a sample of 41 dIm galaxies chosen to span a range of luminosities. We are tracing their stellar populations, gas content, dynamics, and star formation indicators. We were granted over 300 hours of time with the VLA in B, C, and D array configurations to obtain deep HI-line maps of the sample with high angular and velocity resolution to combine with our optical, UV, and IR data to answer the following questions: 1) What regulates cloud/star formation in tiny galaxies? 2) How is star formation occurring in the outer parts of dwarf galaxies, where the gas is gravitationally stable? 3) What happens to the star formation process at breaks in the exponential stellar light profiles? 4) And, what is going on with Blue Compact Dwarfs? More information can be found at http://www.lowell.edu/users/dah/littlethings/. We gratefully acknowledge funding for this research from the National Science Foundation with grants to DAH (AST-0707563) and CES (AST-0707468).

Estelle Bayet (Department of Physics and Astronomy of University College London, UK)

Dr. Maryvonne Gerin (LRA-LERMA-Observatoire de Paris - France)
T.G. Phillips (Caltech Submillimeter Observatory - USA)
Dr. Alessandra Contursi (Max Planck Institute für Extraterrestrische Physik - Germany)

Are the 12CO lines good indicators of star-formation rates in galaxies?

Since late 90's, there has been a lot of work aiming at better describing and understanding the link existing between the reservoirs of molecular gas contained in galaxies and their activity of star-formation. Historically, this study started with the Schmidt-Kennicutt law and its parametrization on local galaxies which led to a power index of about 1.4. However, this relationship does not actually link the **mass** of the molecular gas, more useful quantity, with the star formation rate in galaxies. The last ten years researchers have thus investigated this problem using various tracers of molecular gas (CO(1-0), CO(3-2), HCN(1-0), HCN(3-2), etc...) and different conversion factors (e.g. CO-to-H_2 factor) providing unfortunately a partial answer.

The subject of my talk is to present the first systematic and coherent study of the relationship existing between the CO lines luminosities and the star-formation rate as derived from infrared emission. For the first time, this relationship is studied over a large range of z (from 0 to 6) and over several (twelve) transitions of the same molecule (CO). This work thus provides to the community the most complete study to date on that topic, in terms of line and source samples investigated.

I will present in my talk the slopes and the correlation coefficients defining these observational SFR-CO line luminosity relationships we have obtained. We show that the tightest relationship is found for the high-J CO lines (e.g. CO(6-5), CO(7-6)) making them better indicators of star-formation activity in galaxies than the lower-J CO lines (e.g. CO(1-0), CO(2-1)). These results are compared with the state-of-the-art modelling approaches using 3D non-LTE radiative transfer calculation with hydrodynamical simulation of isolated disk galaxies and galaxy mergers. We confirm observationally what has been inferred by these models that the key quantity to define such relationships is the critical line density as compared to the mean gas density of the studied environment. We however find discrepancies between the predicted and observed SFR-CO line luminosity relationships (slopes) for the high-J CO lines. Several explanations for such discrepancies have been investigated and will be also discussed in details in the talk.

By the tools provided, this study is of particular interest for especially better understand more generally the formation of galaxies in the Universe, especially in the context of ALMA and Herschel.

Guillermo A. Blanc (University of Texas at Austin)

Amanda Heiderman (University of Texas at Austin)
Karl Gebhardt (University of Texas at Austin)
Neal J. Evans II (University of Texas at Austin)
Joshua Adams (University of Texas at Austin)

The Spatially Resolved Star Formation Law from Integral Field Spectroscopy: VIRUS-P Observations of NGC 5194

I will present the first IFU measurement of the spatially resolved star formation law in nearby galaxies. VIRUS-P integral field spectroscopy of the central 4.1 kpc x 4.1 kpc of NGC 5194 (M51) is used to measure Hα, Hβ, [NII]$\lambda\lambda$6548,6584, and [SII]$\lambda\lambda$6717,6731 emission line fluxes for 735 regions $\sim$170 pc in diameter. We use the Balmer decrement to calculate nebular dust extinctions, and correct the observed fluxes in order to measure the SFR surface density in each region. HI 21cm and CO J=1-0 maps are used to measure the atomic and molecular gas surface densities. Line ratios are used to separate the contribution to the Hα flux from the DIG and the HII regions in the disk. We present a new method for fitting the Star Formation Law (SFL), which includes the intrinsic scatter in the relation as a free parameter and allows the inclusion of non-detections in both SFR and gas surface densities. After removing the DIG contribution from the Hα fluxes, we measure a slope $N = 0.82 \pm 0.05$ and an intrinsic scatter $\epsilon = 0.43 \pm 0.02$ dex for the molecular gas SFL. We also measure a typical depletion timescale $\tau = 2$ Gyr, in good agreement with recent measurements by Bigiel et al. 2008. The disagreement with the previous measurement of a super-linear molecular SFL by Kennicutt et al. 2007 is most likely due to differences in the fitting method. Integral field spectroscopy allows a much cleaner measurement of Hα emission line fluxes than narrow-band imaging, since it is free of the systematics introduced by continuum subtraction, underlying photospheric absorption, and contamination by the [NII] doublet. The data shows an excellent agreement with the recently proposed model of the SFL by Krumholz et al. 2009. The large intrinsic scatter observed implies the existence of other parameters, beyond the availability of gas, which are important at setting the SFR.

Charlotte Christensen (University of Washington)

Tom Quinn (University of Washington)
Fabio Governato (University of Washington)

Molecular Hydrogen in Cosmological Simulations of Dwarf Galaxies

The structure and luminosity of dwarf galaxies are highly responsive to the amount of star formation (SF) and stellar feedback occurring during their evolution. This responsiveness makes dwarf galaxies a sensitive environment in which to test the connection between SF and the properties of the host galaxy's cold interstellar medium (ISM). To examine SF in dwarf galaxies, we include the non-equilibrium formation of molecular hydrogen in Smoothed-Particle Hydrodynamic cosmological simulations of galaxies. We calculate the distribution of molecular hydrogen, cold atomic hydrogen gas, and stars in our simulated galaxies and relate the spatial distribution of each. To judge the evolution of SF, we compare the star formation histories of our simulated galaxies to observations and track the fraction of time spent in bursts of SF.

Michelle Cluver (IPAC, Caltech)

Phil Appleton (NHSC, Caltech)
Francois Boulanger (IAS, Orsay)
Pierre Guillard (IAS, Orsay)
Patrick Ogle (SSC, Caltech)

The Shocking Reality of Molecular Hydrogen Cooling in Stephans Quintet

Stephans Quintet is a strongly interacting compact group experiencing a group-wide shock due to the high velocity ($\sim$1000 $\mathrm{km\,s^{-1}}$) collision of an intruder galaxy with the intragroup medium. Extremely strong, pure rotational H_2 emission was recently detected at the centre of the shock-excited filament seen at radio wavelengths. I shall present results from deep, mid-infrared spectral mapping of Stephans Quintet, using the *Spitzer Space Telescope*, that show for the first time the striking abundance and widespread distribution of warm H_2 and confirm the molecular hydrogen emission lines as the dominant cooling pathway in the shock. In the main shock region alone, we find $2.8 \times 10^8\,\mathrm{M_\odot}$ of warm H_2 covering $\sim$480 kpc^2. We additionally report the discovery of a second, major shock-excited feature, likely a remnant of previous tidal interactions, also producing strong pure rotational H_2 emission. This brings the total H_2 line luminosity of the group in excess of $10^{42}\,\mathrm{erg\,s^{-1}}$, exceeding the X-ray luminosity by a factor of ≥ 3. Correlations with other emission lines will be discussed, in particular the close association with [Si II] and the lack of star formation (as traced via nebulae lines or PAH emission) in the main shock. The concordance with a model of H_2 emission driven by turbulent energy transfer, and the prevalence of this pathway over other sources of cooling in fast galaxy-scale shocks, may have important implications for the cooling of gas in the assembly of the first massive galaxies, as well as shock physics in systems ranging from ULIRGs to supernovae remnants

Genevieve de Messieres (University of Virginia)

Robert W. O'Connell (University of Virginia)
Brian R. McNamara (University of Waterloo)
Megan Donahue (Michigan State University)
Paul Nulsen (Harvard-Smithsonian Center for Astrophysics)
G. Mark Voit (Michigan State University)

Spitzer Mid-Infrared Spectra of Cool-Core Galaxy Clusters

We present mid-infrared spectra of the central galaxies in nine massive cool-core X-ray clusters, obtained using the Infrared Spectrograph of the Spitzer Space Telescope. They display strong molecular hydrogen emission, which dominates the spectrum in some cases, but most have weak warm dust continua and PAH emission. With the exceptions of Abell 1068 and Abell 1835 (classic starbursts), the spectra are anomalous compared to normal star-forming galaxies even though most of our sample are known from optical/UV data to be active star-formers. The anomalies may be associated with star formation that occurs at the interface between relativistic jets and the inner cooling flows rather than in a dense disk.

Jacqueline Fischer (Naval Research Laboratory)

Nicholas Abel (University of Cincinnati)
Shobita Satyapal (George Mason University)
Charles Dudley (George Mason University)
Peter van Hoof (Royal Observatory of Belgium)

Dust-Bounded ULIRGs? Model predictions for Infrared Spectroscopic Surveys

In preparation for Herschel, SPICA, and JWST mid- and far-infrared spectroscopic studies, we explore the suggestion that the effects of high ratios of impinging ionizing radiation density to particle density (i.e. high ionization parameters, U) are responsible for many of the infrared spectral properties of ultraluminous infrared galaxies (ULIRGs) such as the faintness of the infrared fine-structure line emission, including the well known "[CII] deficit", and their warm far-infrared colors. We present a theoretical study of the emergent line and continuum properties of a cloud exposed to an ionizing continuum characteristic of an Active Galactic Nucleus (AGN) or starburst, taking into account the ionized, atomic and molecular environments under conditions of pressure balance. For both starburst and AGN input spectral energy distributions, we calculate how the spectrum changes with variations in U and compare the trends found with data in the literature. Our calculations show that high U effects can explain the nearly order of magnitude drop in the [CII]158μm/FIR ratio observed with the ISO LWS in ULIRGs and other warm galactic nuclei with high IRAS F(60μm)/F(100μm) ratios. High U effects also produce increases in the [OI]63μm/[CII] ratio similar to the magnitude of the trends observed, a gradual decline in the [OIII]88μm/FIR and produce a reasonable fit to observations of the [NeV]14μm/FIR ratio in AGN. The effects on absorption in the far-infrared rotational lines of OH and water are also discussed.

Sebastian Haan (Spitzer Science Center, Caltech)

J.A. Surace (Spitzer Science Center, Caltech)
L. Armus (Spitzer Science Center, Caltech)

GOALS NICMOS Imaging: The Nuclear Structure of (Ultra) Luminous-Infrared-Galaxies in the Nearby Universe

Here we present Hubble Space Telescope NICMOS H-band images for the 88 most luminous (U)LIRGs in the Great Observatories All-sky LIRG Survey (GOALS), which combines multiwavelength imaging and spectroscopic data from space (Spitzer, HST, GALEX, and Chandra) and ground-based telescopes. High-resolution near-infrared observations are mandatory to recover nuclear structure that is obscured by dust from view at optical wavelengths. We find that a large fraction of all galaxies in our sample possess double nuclei (35-45%) or show evidence for multiple nuclei and intense star formation regions. Comparison with HST ACS B-band images suggests that half of these double nuclei or nuclear star-formation regions are not visible at short wavelengths due to dust obscuration, placing strong limitations on the ability to detect the true nuclear structures of luminous infrared galaxies at high-redshift. We will discuss the results of the HST near-infrared imaging, and their implications for estimates of the lifetimes of the LIRG phase.

Laura Hainline (University of Maryland)

Andrew Blain (California Institute of Technology)
Ian Smail (Durham University)
Rob Ivison (University of Edinburgh)
Scott Chapman (University of Cambridge)

The Infrared Spectral Energy Distributions and the Infrared-Radio Correlation for Submillimeter-Selected Galaxies

We combine deep imaging at 24 and $70\,\mu m$ with the MIPS instrument on the *Spitzer Space Telescope* with submillimeter photometry of the largest sample of submillimeter-selected galaxies (SMGs) with spectroscopic redshifts to examine the infrared (IR) spectral energy distributions (SEDs) and the far-IR–radio correlation for SMGs. The *Spitzer* data for our sample of ~ 50 SMGs constrain the Wien side of the IR SED peak, and thus are vital to determine the contribution of warm dust emission to the total infrared luminosity. The mid-IR data indicate that while the infrared SEDs of SMGs are non-uniform in shape, the majority of SMGs do not have dominant contributions to their total IR luminosity from warm dust, and confirm that the spectral energy distribution of the nearest ultraluminous IR galaxy, Arp 220, is not representative of SMGs and thus is a poor template with which to predict properties of SMGs. We show with the largest sample of SMGs to date that SMGs follow a tight, nearly linear correlation between IR luminosity and radio luminosity, regardless of AGN/starburst spectral type. We directly compare the IR–radio correlation for high-z SMGs to that of lower-luminosity, local, IRAS-selected star forming galaxies to show that the IR–radio relation for SMGs is consistent with the local relation.

George Heald (ASTRON)

Filippo Fraternali (Bologna University)
Gianfranco Gentile (Universiteit Gent)
Gyula Jozsa (ASTRON)
Eva Juette (Ruhr-Universitaet Bochum)
Tom Oosterloo (ASTRON/Kapteyn Astronomical Institute)
Rich Rand (University of New Mexico)
Renzo Sancisi (Osservatorio Astronomico di Bologna)
Paolo Serra (ASTRON)
Rene Walterbos (New Mexico State University)

The Westerbork HALOGAS Survey

Accretion of cold gas onto galaxies is a crucial part of their evolution, and seems to be necessary to replenish material used up by star formation. Past observations of neutral hydrogen have made clear that a large quantity of cold gas is present in the outer parts of a handful of nearby galaxies. Careful consideration of the kinematics of such gas, and comparison with theoretical work, suggest that a fraction of this gas is in the process of accreting, and that much of the star formation rate can be maintained by the infall of this fresh gas. However, the properties of accreting gas seem to vary substantially among the few galaxies which have so far been observed to sufficient depth. It is not yet clear how many galaxies are presently accreting gas, and what the general properties of accreting gas in the local Universe are. To answer these questions, we have recently started an ambitious program at the Westerbork Synthesis Radio Telescope (WSRT) with the primary goal of characterizing the statistical properties of cold gas accretion through sensitive HI observations of 22 nearby galaxies. I will describe the Westerbork Hydrogen Accretion in Local Galaxies (HALOGAS) Survey, which is presently underway. I will also present the first results from our pilot program, and describe the complementarity between these observations and those to be made with future facilities in understanding the effect of gas accretion on galactic evolution.

Kelley Hess (University of Wisconsin-Madison)

Gas Content and Star Formation in Galaxy Groups of the Coma-A1367 Supercluster

Local environment plays a primary role in determining the evolution of a galaxy's gas and stellar content. Groups of galaxies, in particular, may be the dominant environment in determining galaxy evolution: e.g. the combination of close encounters and major mergers may stimulate star formation and AGN activity, and may be responsible for "pre-processing" of galaxies as they fall into clusters, etc. HI observations of groups and their resident galaxies are a primary tracer of their evolution: its presence is a measure of the star formation potential of a galaxy, and its spatial distribution can reveal the history of recent and on-going interactions between galaxies and with their local environment; while Hα observations of galaxies and groups reveal the presence of current star formation activity. Here, we combine results describing the HI content of the galaxy groups in the Coma-Abell 1367 supercluster from a 2 degree wide strip of the ALFALFA survey centered at +27d from 11h to 13h56m, with Hα observations from the WIYN 0.9 m, in an attempt to understand the evolution of galaxies as a function of their environment. These groups, determined through 2MASS, span a range of global environments from highest density sub-clumps falling into the center of the cluster, to groups of galaxies that make up the filaments between clusters, to poor groups that exist on the edges of voids. By comparing the HI and Hα data we will be able to place the gas and stellar content of galaxies within the evolutionary framework of groups and the supercluster, and examine the interplay between galaxies and their larger environment.

Sukbum Hong (George Mason University)

GALEX Observations of Star-Forming Dwarf Galaxies

We present GALEX observations of 86 star-forming dwarf galaxies. All galaxies are selected from the KPNO International Spectroscopic Survey when they exhibit detectable Hα emission. This sample already possesses optical observations at B, V, and R band images as well as mid-infrared observations at 3.6, 4.5, 5.8, and 8.0 μm imaging from Spitzer. We examine the relationship between star- formation rates computed in the optical, mid-infrared, and UV as a probe of the difference in calibration of the measures and physical properties of the star-forming region including the age of the starburst and possible evidence of the removal of gas and dust from the star-forming regions.

J. Christopher Howk (Univ. of Notre Dame)

Extraplanar Dust in Spiral Galaxies: Probing Galactic Outflows and Infall

Dust is a minor constituent of the interstellar medium by mass, but has disproportionate effects on the thermal balance of the ISM, on the distribution of relative abundances of metals, and on the propagation of UV photons. A decade and more of observations have demonstrated that dust is an important tracer of extraplanar material in spiral galaxies. Most theories for the origin of the extraplanar dust argue for its expulsion from the disk, requiring the dust to be relatively robust to destruction during this process. Thus, dust can be a tracer for matter expelled from the plane, and multiwavelength observations of extraplanar dust can weigh on the mixture of "outflow versus infall" matter in the thick disks and halos of nearby galaxies. I will discuss previous studies of extraplanar dust as well as more recent techniques for probing this tracer of extraplanar material. I will comment on the physical conditions of the material implied by the observations and discuss the origins of the dust and implications for the origins of extraplanar gas.

Minjin Kim (NRAO)

Coevolution of Black Holes and Host Galaxies in Nearby Type I AGNs

We present the M(BH)-L(bulge) relation of broad-line AGNs by analyzing a sample of 237 low-z (< 0.35) AGNs. We derive black hole mass from optical spectra assuming a spherical broad-line region, and bulge luminosity from detailed two-dimensional decomposition of archival optical HST images. We find that our sample roughly follows the M(BH)-L(bulge) relation of inactive galaxies, but the zero-point is offset by $\sim$0.5 dex toward lower BH mass and the slope is marginally steeper than inactive galaxies. At a given bulge luminosity, sources with higher Eddington ratios have lower M(BH). The zero point offset can be explained by a change in the normalization of the virial product used to estimate M(BH), in conjunction with modest BH grwoth ($\sim$10%-40%) during the AGN phase.

Hannah Krug (University of Maryland)

David S.N. Rupke (Institute for Astronomy, University of Hawaii)
Sylvain Veilleux (University of Maryland; Max Planck Institute, Garching)

Neutral Gas Outflows and Inflows in Infrared-Faint Seyfert Galaxies

Previous studies of the NaI D interstellar absorption line doublet have shown that galactic winds occur in most galaxies with high infrared luminosities. However, in infrared-bright composite systems where a starburst coexists with an active galactic nucleus (AGN), it is unclear whether the starburst, the AGN, or both are driving the outflows. The present paper describes the results from a search for outflows in 35 infrared-faint Seyferts with $L_{IR} < 10^{11}$ $L_\odot$, or, equivalently, star formation rates (SFR) below 10 $M_\odot$, to attempt to isolate the source of the outflow. We find that the outflow detection rates for the infrared-faint Seyfert 1s (6%) and Seyfert 2s (18%) are lower than previously reported for infrared-luminous Seyfert 1s (50%) and Seyfert 2s (45%). The outflow kinematics of infrared-faint and infrared-bright Seyfert 2 galaxies resemble those of starburst galaxies, while the outflow velocities in Seyfert 1 galaxies are significantly larger. Taken together, these results suggest that the AGN does not play a significant role in driving the outflows in most infrared-faint and infrared-bright systems, except the high-velocity outflows seen in Seyfert 1 galaxies. Another striking result of this study is the high rate of detection of inflows in infrared-faint galaxies (39% of Seyfert 1s, 35% of Seyfert 2s), significantly larger than in infrared-luminous Seyferts (15%). This inflow may be contributing to the feeding of the AGN in these galaxies, and potentially provides more than enough material to power the observed nuclear activity over typical AGN lifetimes.

Peter Kurczynski (Rutgers University)

Eric Gawiser (Physics Department)
Minh Huynh (IPAC/Caltech)
Thomas R. Greve (Max Planck Institute for Radio Astronomy)
R. J. Ivison (UK Astronomy Technology Centre, Royal Observatory)

Panchromatic SEDs of High-redshift Star-forming Galaxies

We present and analyze the rest-UV-through-radio Spectral Energy Distributions (SEDs) of high-redshift galaxies in the Extended Chandra Deep Field-South. Galaxies are separated into sets by their selection method (Lyman break, Lyman alpha emission, blue rest-UV colors) and into bins of photometric redshift. In order to obtain panchromatic SEDs for each set of galaxies, we performed stacking analyses in Spitzer-MIPS (24, 70 μm), sub-mm (870 μm from the Laboca ECDF-S Sub-mm Survey, LESS), and radio (VLA 1.4 GHz and GMRT 610 MHz). We describe our stacking methods, including an optimized treatment of the deblending of multiple galaxy types in the sub-mm imaging. The resulting SEDs are compared with low-redshift templates of galaxies with a variety of star-forming and AGN properties.

Glen Langston (NRAO)

Katie Chynoweth (NRAO/Vanderbilt)

HVCs: Last Remnants of Galaxy interactions

I will present the most recent results from my Green Bank Telescope HI observations of nearby groups of galaxies. These observations are a search for HI clouds in the galaxy groups and along filaments between groups. This study will constrain models of the High Velocity Clouds (HVCs) that surround the Milky Way. By observing galaxy groups that span the range of interaction and merger activity, we explore the contribution of galaxy interactions to the HVC/HI cloud phenomenon. Additionally, I will present results from numerical simulations of galaxy groups which show the generation of cloud-like structures by galaxy interactions.

James Lowenthal (Smith College)

Extreme starbursts: Spitzer Imaging of luminous blue compact galaxies at $z < 1$

Luminous compact blue galaxies (LCBG) at redshifts $z < 1$ are excellent analogs to Lyman break galaxies (LBGs) at $z > 2$: they are small and low-mass but very luminous systems containing extreme starbursts and showing diverse morphologies. We have obtained Spitzer IRAC and MIPS images of 26 LCBGs, half at $z \sim 0$ and half at $z \sim 0.5$, to measure any dust-enshrouded star formation as a function of dynamical mass and rest-UV size and morphology. We also estimate the galaxies' stellar masses and compare their SEDs to those of both local field galaxies and distant LBGs as we strive to understand the role LCBGs play in overall galaxy evolution.

Irina Marinova (University of Texas at Austin)

Irina Marinova (University of Texas at Austin)
Shardha Jogee (University of Texas at Austin)
Fabio D. Barazza (Laboratoire d'Astrophysique, Ecole Polytechnique Federalede)
Amanda Heiderman (University of Texas at Austin)
STAGES collaboration

The Properties of Local Barred Disks in the Field and Dense Environments: Implications for Galaxy Evolution

Recent results suggest that major mergers play a less important role in driving galaxy evolution since $z \sim 2$ than previously thought. Instead more quiescent processes, such as minor mergers and internal secular evolution may play an important part in galaxy assembly and activity. Bars are the most important internal drivers of evolution and a key step in quantifying the effects of bar-driven secular evolution over the past 8 Gyr, is to determine the frequency and properties of bars in the local Universe in both the field and in dense environments. We present results from three studies: Marinova and Jogee 2007, Barazza, Jogee, and Marinova 2008, and Marinova et al. and STAGES collaboration (2009). We find that the bar fraction among intermediate Hubble types at $z \sim 0$ based on ellipse fits is 44% in the optical and 60% in the NIR, giving an extinction correction factor of approximately 1.4 at $z \sim 0$. We find that at $z \sim 0$, most (68% in the optical and 76% in the NIR) bars have sizes below 5 kpc. If such a distribution of bar sizes is present at a redshift $z \sim 1$–2, then only observations with angular resolutions better than 0.3 arcsec can adequately resolve the majority of bars. We also explore the properties of barred disks in the Abell 901/902 cluster system at $z \sim 0.165$ from the HST ACS survey STAGES. We find that the optical bar fraction is a strong trend of both absolute magnitude and morphological type, increasing for galaxies that are brighter and/or more disk-dominated. The latter trend is also found in the field from SDSS. In addition to having implications for theoretical models of disk galaxy evolution, we discuss how our results provide a low-redshift reference point for ACS surveys out to $z = 1$ in rest-frame optical and for WFC3 and JWST surveys out to $z \sim 3$ in the rest-frame NIR.

Joseph Mazzarella (Caltech)

Kazushi Iwasawa (INAF-Obsservatorio Astronomico di Bologna)
Tatjana Vavilkin (Stony Brook University)
Lee Armus (Caltech)
Aaron Evans (Unitersity of Virginia / NRAO)
GOALS Team

Dual AGNs, Outflow/Feedback, Large-Scale Shocks, and Super Star Clusters in the LIRG Mrk 266

Mrk 266 (NGC 5256) is a Luminous Infrared Galaxy (LIRG, $L_{IR} = 10^{11.5} L_\odot$) involving a major merger between two gas-rich disks. Recent imaging and spectroscopic observations are presented from Spitzer, HST, GALEX, Chandra, and XMM, most of which were acquired by the Great Observatories All-Sky LIRG Survey (GOALS). The data reveal new evidence for gaseous outflow/feedback ranging from 0.2 kpc (inside the NLR) to 20 kpc (a galactic scale superwind), previously unknown properties of shock-excited gas concentrated between the colliding disks and dispersed throughout the superwind, and ∼100 super star clusters and associations. I will discuss these new results in the context of merging spiral galaxies evolving through luminous and ultraluminous infrared phases that involve large-scale winds, shocks and AGN ejecta that can dramatically alter the ISM. Being one of just a few (U)LIRGs in the local universe with confirmed high-luminosity, dual AGNs, Mrk 266 also has a lot to teach us regarding the origin of supermassive binary blackholes observed (or suspected) in some quasars and powerful radio galaxies.

Jesse Miner (UNC-Chapel Hill)

James A. Rose (UNC-Chapel Hill)

A new NIR chronometer with application to high redshift galaxies

New and future space observatories, such as the Herschel Space Observatory and the James Webb Space Telescope, will offer astronomers unprecedented access to rest-frame infrared light from the first generation of galaxies. This is especially exciting because recent advances in the treatment of stars on the Thermally-Pulsing Asymptotic Giant Branch (TP-AGB) in stellar population models have indicated that there are unique infrared spectroscopic features in young ($\sim$100 Myr) and intermediate age ($\sim$1 Gyr) stellar populations. We will present ongoing work to calibrate these age-sensitive features with optical and near-infrared spectroscopic studies of nearby galaxies in order to develop an age-dating technique applicable to high redshift objects. Our approach is as follows: we obtain both optical and infrared spectroscopy of a sample of galaxies and use established optical techniques to determine the age and composition of the underlying stellar populations, and also measure the IR features predicted by recent models. The results from the optical measurements will be used to calibrate the IR features, in order to develop a NIR chronometer which will be particularly sensitive to galaxies with intermediate age stellar populations, thus making it particularly relevant for high redshift objects. The calibration is necessary because the features are due to contribution from evolved stars, whose fundamental properties are not well understood, and it will be a useful test of the predictive power of the new stellar population models. Our first thoroughly-studied object is NGC 5102, which has both a very young and an intermediate age stellar component, and thus will contain a large population of TP-AGB stars. Age measurements from optical spectroscopy of NGC 5102, and the predicted NIR features will be discussed.

Amanda Moffett (University of North Carolina)

Sheila Kannappan (University of North Carolina)
Seppo Laine (Spitzer Science Center)
Lisa H. Wei (University of Maryland)
Andrew J. Baker (Rutgers University)
Chris D. Impey (University of Arizona)

Extended Light in E/S0 Galaxies and Implications for Disk Rebirth

The recent discovery of extended ultraviolet (XUV) disks around ordinary disk galaxies provides evidence for disk building at recent epochs. Combining GALEX UV observations with Spitzer IR and deep optical imaging, we search for XUV disks in a sample of nearby low-to-intermediate mass E/S0 galaxies to explore evidence for disk rebuilding after mergers. Preliminary visual classification yields ten XUV-disk candidates from the full sample of 30, intriguingly similar to the late type fraction of ~30%. These XUV candidates occur at a wide range of masses and on both the red and blue sequences in color vs. stellar mass, indicating a possible association with processes like gas accretion and/or galaxy interactions that would affect the galaxy population broadly. We go on to apply the quantitative Type 1 and Type 2 XUV-disk definitions to a subsample analyzed in detail. In this possibly non-representative subsample, we identify multiple Type 1 XUVs, i.e. galaxies with UV structure beyond the expected star formation threshold. We also find several galaxies that come close to satisfying the Type 2 definition, but it proves problematic to apply to this sample: the NUV-derived star formation threshold radii for our E/S0s often lie inside the 80% Ks-band light radii K80, violating an implicit assumption of the Type 2 definition, or lie outside but not as far as the definition requires. Nonetheless, we find otherwise Type 2-like galaxies that have higher star formation rates and bluer FUV - NUV colors than Type 1 XUVs in the sample, perhaps reflecting inside-out disk regrowth.

Sean Moran (Johns Hopkins University)

Tim Heckman (JHU)
Barbara Catinella (MPA)
David Schiminovich (Columbia)
Guinevere Kauffmann (MPA)

Tracing Star Formation, HI Content, and Dynamics Across the Green Valley: Resolved Spectroscopy of Galaxies in GASS, the GALEX-Arecibo-SDSS Survey

We present initial results from our campaign to acquire longslit spectroscopy of galaxies in GASS, an Arecibo HI survey aiming to measure the gas content of a volume-limited sample of 1000 galaxies in the range 0.025<z<0.05. The GASS sample spans the critical 'transition' mass separating star forming galaxies from passive red sequence galaxies. Earlier SDSS fiber spectra cover only the central few kpc of galaxies at these redshifts, and so provide no insight into the current and recent star formation histories of outer disks, where most star formation and most of the gas resides. Therefore, we have been pursuing a followup campaign of resolved longslit spectroscopy in order to make progress in relating these galaxies' recent star formation histories and internal dynamics to their total HI content. We trace these quantities to beyond one scale length in each galaxy, and our initial results uncover a number of peculiar cases of both HI deficient galaxies with extended ongoing star formation and seemingly quiescent red-sequence galaxies with copious HI. A statistically significant number of galaxies in the green valley fall into one of these two categories, and we will discuss the implications for the frequency and mechanisms of quenching or revival of star formation across the blue/red divide.

Juergen Ott (National Radio Astronomy Observatory, Socorro, NM, USA)

Tony Wong (University of Illinois, Urbana, IL, USA)
Jorge Pineda (Jet Propulsion Laboratory, Pasadena, CA, USA)
Annie Hughes (Swinburne University of Technology, Melbourne, Australia)
Erik Muller (Nagoya University, Nagoya, Japan)

Bridging Local and Global Scales: Molecular Cloud and Star Formation in the Magellanic Clouds

The Magellanic Clouds are the first milestone to understand molecular cloud and star formation on galaxy-wide scales. The Large Magellanic Cloud (LMC) exhibits an inclination that allows the detailed distribution of the giant molecular clouds (GMCs) while retaining the kinematic information (in contrast to the Galaxy). The Magellanic System is also close enough to identify all individual GMCs and thus provide enough objects to derive the statistical properties of their populations. We present CO observations with a resolution of 10pc of all GMCs in the LMC and deep observations of GMCs in the Small Magellanic Cloud (SMC). In addition, we will show interferometric observations of high density tracers (HCN, HCO+) towards a number of individual star forming regions at 2 pc resolution. We find that a simple column density argument is not sufficient for the transformation of atomic into molecular gas. It also appears that the radiation field that surrounds the molecular material only has little influence on most of the properties and thus the star formation abilities of individual GMCs. A trend, however, between the radiation field and the surface density of molecular material may exist. With the molecular gas being decoupled from the pressure equilibrium of their surroundings, the problem of star formation turns into a problem of molecular cloud formation. We will show how the GMC formation may depend on the global structure of a galaxy. Given the low metallicities of the Magellanic Clouds, our studies may have immediate impact in the understanding of 'normal' galaxies at high redshift. With their southern location, and their proximity that connects Galactic and extragalactic studies, the Magellanic System will be a prime target for future ALMA experiments.

Kyle Penner (University of Arizona)

Dennis Zaritsky (University of Arizona)

Gas in Disk Galaxies on the Fundamental Manifold

The Fundamental Manifold unifies the Tully-Fisher and Fundamental Plane scaling relations. The only galaxies found to deviate from the manifold are gas rich galaxies. We investigate the nature of these deviations using HI masses for a broad sample of local galaxies. Our goal is to recast the Fundamental Manifold in a form that is valid for all galaxies, and by doing so, gain some structural understanding of how galaxies convert their gas into stars.

D.J. Pisano (West Virginia University)

Catherine Garland (Castleton State College, Vermont)
Rafael Guzman (University of Florida)
Jorge Perez-Gallego (University of Florida)
Francisco Javier Castander (Institut de Ciencies de lEspai, Barcelona, Spain)

The evolution of luminous compact blue galaxies: disks or spheroids?

Luminous compact blue galaxies (LCBGs) are a diverse class of galaxies characterized by high luminosities, blue colors, and high surface brightness. While they were relatively common at a redshift of one, and contribute a significant fraction to the star formation rate density at the time, they are a factor of ten rarer today and contribute negligibly to the current star formation rate density. As such, they are one of the most rapidly evolving populations of galaxies in the Universe. Given their location at the high luminosity, high mass end (halo masses less than 10^{12} solar masses) of the blue sequence, LCBGs sit at the critical juncture of galaxies that are evolving from the blue to the red sequence. However, we do not yet understand how these galaxies evolve nor their end products. To start answering these questions, we are conducting a multi-wavelength survey of rare, local LCBGs selected from the SDSS to be analogous to the common, distant LCBGs. We will present the results from single-dish and interferometic HI observations of local LCBGs and their implications for the evolution of local and distant LCBGs. Our data show that LCBGs have a diverse range of HI properties. They are characterized by HI masses similar to the Milky Way and dynamical masses similar to M33, yet they have gas depletion timescales of less than 2 Gyr. This is consistent with LCBGs evolving into low-mass spiral galaxies or high-mass dwarf ellipticals. However, despite the presence of large amounts of HI and signatures of normal rotation, LCBGs do not follow the Tully-Fisher relation. Furthermore, HI maps of many LCBGs show signatures of recent interactions and dynamically hot components, suggesting that we are seeing the formation of a thick disk or spheroid in at least some LCBGs. Finally, combined with optical spectroscopy, these data suggest that star formation in LCBGs is primarily quenched by virial heating, consistent with model predictions.

Nurur Rahman (Dept of Astronomy, University of Maryland)

Alberto Bolatto (Dept of Astronomy, University of Maryland)

Resolved Star Formation Law in NGC 4254

An accurate knowledge of star formation law is crucial to make progress in understanding galaxy formation and evolution. We are studying this topic using CARMA STING (Survey Toward Infrared-bright Nearby Galaxies), an interferometric CO survey of a sample of 27 star-forming nearby galaxies with a wealth of multi-wavelength data designed to study star formation in environments throughout the blue sequence at sub-kpc scales.

We will present results for NGC 4254 (M99), one of our sample galaxies. We construct star formation rate surface density (SFRSD) and gas (atomic and molecular) surface density indicators using a combination of high resolution data from KPNO, Spitzer, IRAM, CARMA, and VLA.

Richard Rand (University of New Mexico)

Sharon E. Meidt (MPIA Heidelberg)
Kenneth Wood (Univ. of St. Andrews)
Robert A. Benjamin (Univ of Wisconsin-Whitewater)

A Spitzer Spectroscopic View of Galaxy Halos

Optical emission line ratios have provided much information on the ionization and energetics of gaseous halos. However, their interpretation is complicated by temperature, abundance and extinction variation. The Spitzer Space Telescope allows measurement of the infrared [Ne III]/[Ne II] ratio, which is essentially free of these complications and provides a straightforward measure of halo radiation field hardness. We report such measurements for the halos of the edge-ons NGC 891, NGC 5775 and NGC 3044. In the first two cases, optical line ratios cannot be explained simply by ionizing radiation leaking out of the disk. The neon ratio is higher in the halo than in the disk in both galaxies, presenting further serious problems for pure photo-ionization models. Scatter in the disk values for NGC 3044 prevent firm conclusions from being drawn. The spectra also allow PAHs in the halos to be studied. In NGC 891 and NGC 5775, scale heights for PAH features in the 10-20 micron range are comparable to those of the main HI layers. In NGC 891, the 8 micron scale height is significantly lower, suggesting a drop in PAH ionization with height. For all three galaxies, most equivalent widths are higher in the halos, suggesting a subtle change in the PAH population.

Amy Reines (UVa)

A New View of the Super Star Clusters in the Low-Metallicity Galaxy SBS 0335-052

We have conducted a detailed multi-wavelength study of the individual super star clusters (SSCs) in SBS 0335-052, a blue compact dwarf galaxy well-known for its extremely low oxygen abundance and high star formation rate. New near-IR and archival optical HST observations, as well as radio continuum measurements from the VLA, are used to probe the stellar populations and the gaseous and dusty birth cocoons of the infant SSCs. The primary goal of this study is to investigate SSC formation and early evolution in an environment similar to that which might be found in primordial galaxies during the time ancient globular clusters were prolifically formed throughout the universe.

Jane Rigby (Carnegie Observatories)

Lensed star-forming galaxies at 1<z<3

Much of the Universe's stars formed in major starbursts at 1<z<3. At present, detailed spectroscopy can only be obtained for rare starbursts that have been gravitationally lensed. Spitzer spectroscopy of 15 such lensed galaxies illustrates that the spectra have evolved dramatically between z=0 and z=2. This result has important consequences for star formation rate calibrations. Moreover, the spectral evolution strongly suggests that star formation at high redshift was not as heavily obscured as in local analogues, the z=0 ultraluminous infrared galaxies (ULIRGs). As such, z=0 ULIRGs may be misleading examples of how starbursts worked at high redshift.

Another way to probe the detailed workings of high redshift starbursts is through rest-UV spectroscopy. I will present new Magellan spectra that probe the stellar populations, interstellar media, and outflows of average star-forming galaxies at z=2-3.

At present, only strongly-amplified galaxies are bright enough for this work. JWST and twenty-meter optical telescopes will extend these studies to large samples of unlensed field galaxies, and ALMA will reveal how gas is driven in to fuel these starbursts.

Joel Roediger (Queens University)

Stephane Courteau (Queens University)
Michael McDonald (University of Maryland)
Lauren A. MacArthur (Herzberg Institute of Astrophysics)

The History of Stellar Mass Assembly in the Virgo Cluster

Through a combination of optical and deep, near-infrared photometry for a statistically-complete sample of Virgo cluster galaxies, we have achieved an ideal laboratory for the simultaneous study of stellar populations across the multi-dimensional spectrum of galaxian parameter space. We use the evolution models of Bruzual & Charlot (2003) to determine best-fit mean ages and metallicities for the stars in these galaxies. The properties of the stellar populations which we determine are compared against galaxies of different types/concentrations, various galaxian parameters (e.g. V_{circ}) and cluster-centric position to better understand what controls star formation and chemical evolution in the cluster environment. Searching for such correlations also provides constraints in the development of a global picture of the formation and evolution of galaxies of different types. We also present preliminary efforts towards building 2D age/metallicity maps for the galaxies in our sample, which will offer a more complete picture of galaxy evolution, particularly with respect to environmental effects.

Jessica Rosenberg (George Mason University)

Sukbum Hong (George Mason University)
John J. Salzer (Indiana University)
Matthew Ashby (Harvard-Smithsonian Center for Astrophysics)

Current and Future Observations of Star-Forming Dwarf Galaxies

Star forming dwarf galaxies are low luminosity systems that exhibit significant amounts of star-formation indicated by their Hα emission. We have studied the mid-infrared and UV properties of a sample of these systems selected from the KPNO International Spectroscopic Survey. This sample is complete and has a well defined selection function that allows us to determine the space and luminosity densities of these objects including their contribution to the star formation rate density and the 8 μm luminosity density. I will discuss these observations and what they tell us about these galaxies which have some of the lowest metallicities in the local universe. In addition, these systems may share properties with a class of infrared faint Lyman Break galaxies at higher redshift. Observations with ALMA, Herschel, and JWST promise to teach us more about these galaxies at low redshift and probe their connection with galaxy populations in the more distant universe.

Barry Rothberg (Naval Research Laboratory)

Jacqueline Fischer (Naval Research Laboratory)

Dynamical Discrepancies in LIRGs/ULIRGs: Anemic Galaxies or Misrepresented Populations?

A key goal in astrophysics is the ability to identify the progenitors of present-day galaxies and their transformative processes. Mergers in the local universe present a unique opportunity for studying these metamorphoses in detail. Yet, many studies and simulations show gas-rich mergers do not contribute significantly to the overall star-formation rate and total mass function of galaxies. The ultimate implication is that Λ-CDM and our current understanding of galaxy formation and evolution may be completely wrong. I will discuss recent results, based on high-resolution imaging and multi-wavelength spectroscopy, which demonstrate how star-formation and the presence of multiple stellar populations has lead to a serious underestimation of the dynamical masses of star-forming galaxies, in particular, Luminous and Ultraluminous Infrared Galaxies. The dominance of Red Supergiants and Asymptotic Giant Branch stars in the near-infrared bands, where dust obscuration does not block their signatures, can severely bias the global properties measured in a galaxy, including: mass, age, extinction, and star-formation rate. I will also discuss the impact of these stellar populations on studies of high redshift galaxies.

Kurt Soto (University of California Santa Barbara)

Crystal Martin (University of California Santa Barbara)

Stellar Population Gradients in Ultra Luminous Infrared Galaxies: Estimating the Merger Driven Gas Depletion Time Scale

Optical spectroscopy using the echellete spectrograph and imager (ESI) on Keck II are presented for nearby major mergers of gas-rich galaxies. These Ultra Luminous Infrared Galaxy spectra show strong A star features and Hα emission, indicating recent starburst activity. We find that the strength of the Hβ absorption line increases with the projected distance from the center of the merger. We interpret this Hβ equivalent width as a measure of the time since star formation was suppressed, indicating older populations in the outer regions of the merger remnant. The time since truncation of star formation in the outer regions increases in each object, while star formation in the central kpc is consistent with continuous star formation. We interpret this result as evidence that gas depletion occurs first in the outer disk, likely due to merger-induced gas inflow. Our empirical constraint on the gas inflow timescale is central to modeling merger-induced star formation and AGN activity. Theoretical models accurately predict the total amount of infalling gas but simply guess the timescale.

Henrik Spoon (Cornell University)

Joanna Holt (Leiden Observatory)

Mid-IR kinematic evidence for outflows in ULIRGs

We report on the results of a first systematic study of the line profiles of the mid-infrared fine-structure lines of Ne+, Ne2+, Ne4+ and Ne5+ (21-127 eV) in a sample of 200 ULIRGs, HyLIRGs, Seyferts, QSOs and starburst galaxies observed in the high-resolution mode (R=600) of Spitzer-IRS. The sources span a range of 5 decades in [Ne V] AGN luminosity and 6 decades in 21cm radio luminosity. We detect resolved line emission in the majority of ULIRGs, most notably in those with an optical Seyfert classification. Comparison of the velocity line profiles of different ionization stages indicates a gradual increase of ionization with increasing blue shift for part of our sample, whereas for other sources all neon lines have similar profiles. We further find a correlation between the FW20 and the line luminosity for the [Ne III] and [Ne V] lines. ULIRGs, the radio-loud ones especially, appear to form the high-luminosity end of this correlation.

David Stark (University of North Carolina, Chapel Hill)

Gas-Dominated Galaxies and the Baryonic Tully-Fisher Relation

Gas-rich galaxies can be extremely useful tools in understanding galaxy structure and evolution. I will show results of a recent study where we calibrated the Baryonic Tully-Fisher (BTF) relation using a sample of gas dominated galaxies. These can determine the absolute scale of the baryonic mass–rotation speed relation independent of the choice of stellar mass estimator. Using gas masses derived solely from HI, we find a BTF relation consistent with several past studies that used primarily star-dominated galaxies. This approach can be used to put an independent constraint on the stellar mass zero point in population synthesis models. However, as the zero point remains uncertain, H_2 measurements are necessary to refine this method. IRAM, and soon ALMA, will put better constraints on the total gas mass of these galaxies. Further, recent dynamical studies of gas-rich galaxies have revealed the potential presence of missing baryons in extremely blue galaxies, possibly in the form of WHIM or ultra-cold molecular hydrogen. Constraining this additional component will also be important in obtaining the most accurate calibration of the BTF relation possible from gas dominated galaxies. Finally, the arrival of ALMA and the EVLA will allow the extension of this approach to gas dominated galaxies at higher redshift, building on pioneering studies of the CO Tully-Fisher relation.

Sabrina Stierwalt (Spitzer Science Center, Caltech)

An HI-selected Sample of Low-mass Dwarf Galaxies in the Nearby Leo I Group

In 20% of its intended coverage, the ongoing, blind HI survey ALFALFA has already made >300 detections with log(MHI)<8.0, many of which are very low surface brightness and were previously uncatalogued. Due to superior sensitivity and spectral resolution, ALFALFA is dramatically increasing the number of known dwarf galaxies in the local universe and probes the low-mass end of the HI mass function (HIMF) for the dwarf systems believed to be the building blocks of galaxy formation. At ~10.5 Mpc, the Leo I group presents a nearby group environment well-suited for finding the lowest mass galaxies detectable outside of the Local Group. Although optical surveys find the Leo I environment lacking in dwarf galaxies, we derive from the complete ALFALFA sample in Leo I the only HIMF to date dominated by low-mass systems with 45 galaxies of log(MHI)<8.0, and compare with HIMFs previously derived for other nearby groups. However, we still find a shallower low-mass slope than that predicted by simulations of dark matter halo formation which suggests a population of gas- rich, low surface brightness galaxies does not solve the discrepancy between simulations and observations. Leo I is characterized by a low velocity dispersion (~175 km/s) despite the presence of E/S0 galaxies more typical of dense clusters. The group's proximity and intermediate density offer a unique basis for comparison of observed trends among Local Group dwarfs that offer key information to our understanding of dwarf galaxy evolution. An investigation of such trends, like morphological segregation and the dwarf galaxy metallicity-luminosity relation for the HI-selected gas-rich, yet still very low-mass dwarfs of the Leo I group will be presented. We will also discuss the potential of the ALFALFA survey as a whole for identifying tidal dwarf galaxies and for determining their contribution to the number of dwarfs observed at the current epoch as evidenced by our findings in Leo I.

Adrienne Stilp (University of Washington)

Juergen Ott (NRAO)
Steven Warren (University of Minnesota)
Julianne Dalcanton (University of Washington)
Evan Skillman (University of Minnesota)
Fabian Walter (Max Planck Institut fr Astronomie)

Rolling Back the Clock: Star Formation and the ISM over Timescales of 1 Gyr

The interplay of star formation and the ISM is critical for shaping the baryonic component of galaxies. However, most current studies focus on studying only part of the ISM-star formation feedback cycle, and are concerned primarily with how the current properties of the ISM are connected to the current star formation rate. Equally important, however, is how the present state of the ISM has been shaped by past star formation. Recent episodes of star formation can potentially alter the kinematics and phase of the ISM, while leaving few traces in commonly used star formation indicators (H_α, FUV, etc). Thankfully, HST gives us the means to accurately constrain recent star formation histories on timescales up to 1 Gyr, using CMDs of individual stars imaged at high angular resolution. We have obtained VLA multi-configuration observations in an NRAO Large VLA program (VLA-ANGST, PI = Ott) for a volume-limited sample of galaxies within 4 Mpc that also has extensive HST imaging from the ACS Nearby Galaxy Survey Treasury (ANGST). The combination of ANGST/HST and VLA data allows us to understand the impact of star formation on the ISM, including the triggering of star formation, the feedback of massive stars, and the energy budget of of the ISM on local and galaxy scales. I will present an overview of the current state of the survey, as well as preliminary results on the correlation between the star formation history and the velocity dispersion in select galaxies.

Jason Surace (Spitzer Science Center/Caltech)

The GOALS Team

The Optical Morphology of Luminous Infrared Galaxies at z∼0 and z∼1

Luminous and Ultraluminous Infrared Galaxies are host to extreme star formation and are commonly invoked as models of galaxy formation. Their optical structure provides clues as to their dynamical state and the distribution of star formation within them. We discuss here comparative morphology derived from the GOALS survey (at redshift near zero) and the COSMOS survey (near redshift 1), and associated implications for the formation of these systems.

Stephanie Tonnesen (Columbia University)

The Tail of the Stripped Gas that Cooled: Observational Signatures of Ram Pressure Stripping

Galaxies moving through the intracluster medium of a cluster of galaxies can lose gas via ram pressure stripping. This stripped gas forms a tail behind the galaxy which is potentially observable. We carry out hydrodynamical simulations of a galaxy undergoing stripping with a focus on the gas properties in the wake and their observational signatures. We include radiative cooling in an adaptive hydrocode in order to investigate the impact of a clumpy, multi-phase interstellar medium. We find that including cooling results in very different morphologies for the gas in the tail, with a much wider range of temperatures and densities. The tail is significantly narrower in runs with radiative cooling, in agreement with observed wakes. In addition, we make detailed predictions of HI, Hα and X-ray emission for the wake, showing that we generally expect detectable HI and Hα signatures, but no observable X-ray emission (at least for our chosen ram-pressure strength and ICM conditions).

Tomoka Tosaki (Joetsu University of Education)

Kotaro Kohno (Institute of Astronomy, The University of Tokyo)
Kazuyuki Muraoka (Nobeyama Radio Observatory)
Kohichiro Nakanishi (National Astronomical Observatory of Japan)
Rie Miura (Department of Astronomy, The University of Tokyo)

ASTE Dense gas Imaging of Star-forming galaxies(ADIoS)

We present recent results of "ASTE Dense gas Imaging of Star-forming galaxies(ADIoS)". Dense molecular gas is one of essential components for star formation in galaxies. In order to understand the global distribution of a dense molecular gas in galaxies, we have conducted an extragalactic CO(3-2) imaging survey of nearby star forming galaxies using the Atacama Submillimeter Telescope Experiment (ASTE). For now, the targets of our survey are nine (or ten) galaxies; the local group galaxies (M31, M33, NGC 6822), nearby active galaxies (M83, NGC 253, NGC 986, Cen A, NGC 1365) and interacting galaxies (NGC 4567/4568).

NGC 6822, one of the target of the survey, is dwarf irregular galaxy in the local group, and includes several star forming regions. Individual GMCs in the galaxy can be resolved, since ASTE beamsize, 22 arcsec, corresponds to 20 pc, which is smaller than the typical size of the Galactic GMCs. We observed three GMCs in NGC 6822, which show different activity of star formation. Each GMC show different CO(3-2)/CO(1-0) ratio and the GMC with higher CO(3-2)/CO(1-0) ratio shows more active and/or more evolved in star formation.

Based on these results, we will discuss a CO(3-2)/CO(1-0) ratio as indicators of dense gas fraction and/or evolutional stages along star formation.

Sarah Tuttle (Columbia University)

First Results from FIREBall: Searching for the CGM using emission

FIREBall (Faint Intergalactic Redshifted Emission Balloon) is a balloon borne experiment designed to observe the IGM and CGM through ultraviolet emission. The science instrument on the 1m telescope is a fiber fed integral field unit. 250 independent spectra are taken over the 160 arcmin in diameter field. The instrument exploits current UV technology to create three dimensional views of the gas between galaxies.

A successful science flight took place in June of this year. Details of the flight and initial results will be shown.

Vivian U (Institute for Astronomy, University of Hawaii)

David Sanders (Institute for Astronomy, University of Hawaii)
Aaron Evans (University of Virginia / NRAO)
Joseph Mazzarella (IPAC / Caltech)
Lee Armus (Spitzer Science Center / Caltech)
Michele Dufault (Yale University)

SED Analysis of Luminous Infrared Galaxies

Luminous and ultraluminous infrared galaxies (LIRGs and ULIRGs) are important transition objects between young, blue spirals and old, red ellipticals in the context of galaxy evolution. Their bulk multiwavelength properties are usually exemplified by the spectral energy distribution (SED) of Arp 220, the "poster child" of ULIRGs. However, there in fact exists a range of spectra shapes for these infrared-luminous objects that cannot be represented by a single template. Here we present comprehensive SEDs for a sample of local (U)LIRGs from the Revised Bright Galaxy Sample (RBGS). Our sample spans the luminosity range $11.1 < \log(L_{\mathrm{IR}}/L_\odot) < 12.5$. To complement spacecraft (*Chandra, GALEX, HST, Spitzer*) data from the Great Observatories All-sky LIRG Survey (GOALS), we also compiled optical/infrared/submm/radio imaging data from Mauna Kea and from literature to construct full SEDs. We characterized the spectral shapes of these SEDs and analyzed the ratios of the radio, infrared, optical, and x-ray emission as a function of infrared luminosity. Trends observed in various alpha indices will be discussed.

Tatjana Vavilkin (Stony Brook University)

A. Evans (NRAO / U. Virginia)
J. Mazzarella (IPAC, Caltech)
J. Surace (SSC, Caltech)
D. Kim (U. Virginia)
L. Armus (SSC, Caltech)

Star Formation in Luminous Infrared Galaxies as Traced by GALEX, HST and Spitzer

Luminous Infrared Galaxies (LIRGs) are believed to play an important role in the star formation history of the Universe. Locally, LIRGs are observed to undergo intense bursts of star formation primarily as a result of interaction/merger process. In this talk, I present high-resolution optical Hubble Space Telescope ACS observations of 11 nearby (z < 0.3), cluster-rich LIRGs in the Revised Bright Galaxy Sample (RBGS). The $\sim 0.1''$ resolution of this dataset allows for the best possibility thus far to study the properties of star-forming clusters and associations in these luminous IR systems at various interaction stages. Ancillary Spitzer IRAC and GALEX near-UV imaging data are also presented to allow an assessment of the morphology and spatial distribution of star-forming regions at these wavelengths, and to correlate locations of young optical stellar clusters with PAH and UV emission regions. This work is part of the Great Observatories All-sky LIRG Survey (GOALS).

Lisa May Walker (UVa)

Mid-Infrared Evidence for Accelerated Evolution in Compact Group Galaxies

We find evidence for accelerated evolution in compact group galaxies from the mid-infrared distribution in colorspace of 42 galaxies from 12 Hickson Compact Groups (HCGs) and the distributions of several comparison samples including the LVL+SINGS galaxies, interacting galaxies, and galaxies from the Coma Cluster. We find that the HCG galaxies are not uniformly distributed in colorspace, as well as quantitative evidence for a gap. Galaxies in the infall region of the Coma cluster also exhibit a non-uniform distribution and a less well defined gap, which may reflect a similarity with the compact group environment. Neither the Coma Center or interacting samples show evidence of a gap, leading us to speculate that the gap is unique to the environment present in compact groups and cluster outskirts; one of high galaxy density where gas has not been fully processed or stripped.

Steven Warren (University of Minnesota)

Daniel Weisz (University of Minnesota)
Juergen Ott (NRAO)
Adrienne Stilp (University of Washington)
Evan Skillman (University of Minnesota)
Julianne Dalcanton (University of Washington)

Connecting Past Star Formation to Current HI Structures

Star formation histories (SFHs) derived from resolved stellar populations have changed the way we can look at galaxies. New techniques that combine the information from SFHs and blue helium burning stars have allowed us to produce spatially resolved ($\sim 8''$) SFH maps. These maps give us the unique opportunity to study past star forming events that may have helped shape the current HI distribution. We combine the SFHs computed from data taken with the Hubble Space Telescope with VLA HI line data (The HI Nearby Galaxy Survey $-$ THINGS) to gain insight into the fundamental processes that create large, HI$-$deficient holes or shells in the interstellar medium. The resolution from the THINGS VLA data ($\sim 7''$) perfectly compliment the SFH maps. Extending the work done by Weisz and collaborators on IC 2574 and Holmberg II, we present preliminary results for two M81 Group dwarf galaxies: M81 dwarf A and Holmberg I. At first glance, the HI distributions of both galaxies appear similar; each contain a ring of high surface brightness gas around a central cavity. Star formation over the past ~ 500 Myr was at a relatively constant level in both galaxies. However, M81 dwarf A's star formation is centrally concentrated while Holmberg I's permeates through the entire HI disk. We present analysis of the timing, location, and energy associated with SF to explore the connection between stellar feedback and the large HI cavities present in both galaxies. This is a pilot project which will be extended to many more dwarf galaxies with data taken for the NRAO Large Project, VLA-ANGST (P.I. Ott).

Yoshimasa Watanabe (Hokkaido University, Japan)

Kazuo Sorai (Hokkaido University, Japan)
Nario Kuno (Nobeyama Radio Observatory)
Tomoka Tosaki (Joetsu University of Education)
Tetsuhiro Minamidani (Hokkaido University, Japan)

Multi-line molecular gas observations and star formation in the nearby barred spiral galaxy NGC 3627

We present results of ^{13}CO($J=1-0$) and ^{12}CO($J=3-2$) observation of the nearby barred spiral galaxy NGC 3627 with the Nobeyama 45 m telescope and the Atacama Submillimeter Telescope Experiment (ASTE).

We detected ^{13}CO($1-0$) emission in the positions where ^{12}CO($1-0$) emission was detected in the Nobeyama CO Atlas (Kuno et al. 2007). We find that the ^{12}CO($1-0$)/^{13}CO($1-0$) ratios ($R_{12/13}$) are higher in a bar ($R_{12/13} \sim 25$) than in spiral arms and bar ends ($R_{12/13} \sim 10$-15). Star formation efficiency (SFE) of NGC 3627 derived from Hα, mid-IR 24 μm and ^{12}CO($1-0$) data are $\sim 1.0 \times 10^{-9}$ yr^{-1} in the bar, $\sim 2.0 \times 10^{-9}$ yr^{-1} in the spiral arms and $\sim 5.0 \times 10^{-9}$yr^{-1} in the bar ends, which suggests SFE is low in the bar compared with other regions. But there is little difference between the bar and the spiral arms, if we estimate SFE from the ^{13}CO($1-0$) intensity. We suppose to overestimate a column density of molecular gas due to higher optical depth of the ^{12}CO($1-0$) line than the ^{13}CO($1-0$) line, which leads to the SFE estimated from the ^{12}CO($1-0$) to be lower value. The bar ends, however, remain to have twice higher SFE than the other regions, even though we use ^{13}CO($1-0$) to estimate molecular gas mass.

Emission of ^{12}CO($3-2$) line was detected in the center, the bar, the bar end and the spiral arms. In the bar end, peak positions of ^{12}CO($3-2$) / ^{12}CO($1-0$) ratio ($R_{3-2/1-0}$), which traces dense molecular gas fraction, are located in the leading side of ^{12}CO($1-0$) intensity peaks which almost coincide with ^{12}CO($3-2$) peaks at the bar end. We interpret the above picture as follows: the molecular gas assembles at the bar end, then streams forward and becomes dense at the leading side of the bar end where SFE is high value.

Lisa Wei (University of Maryland)

Sheila J. Kannappan (University of North Carolina)
Stuart N. Vogel (University of Maryland)
Andrew J. Baker (Rutgers University)

Gas Mass Fractions and Disk Regrowth Potential in Local Blue-Sequence E/S0s

Recent work has identified a population of local E/S0 galaxies that lie on the blue sequence in color vs. stellar mass parameter space, where spiral galaxies typically reside. While high-mass blue-sequence E/S0s may often be young merger/interaction remnants likely to fade to the red sequence, we focus on blue-sequence E/S0s with lower stellar masses ($M_* <$ few $\times 10^{10}\ M_\odot$), which are characterized by fairly regular morphology and low density field environments where fresh gas infall is possible. This population may provide an evolutionary link between traditional early type galaxies and spirals through disk regrowth. Based on new GBT and VLA data for a representative sample of E/S0s, the atomic gas to stellar mass ratios for most blue-sequence E/S0s range from 0.1 to 1.0, comparable to those of spiral and irregular galaxies. Assuming that the HI is accessible for star formation, we find that at least half of our blue-sequence E/S0s can increase their stellar masses by 10-50% in 2 Gyr either of two extreme scenarios, exponentially declining star formation (i.e. closed box) or constant star formation (i.e. allowing gas infall). We present evidence that star formation in these galaxies is bursty and likely involves externally triggered gas inflows. We also present CARMA CO 1-0 maps of select blue-sequence E/S0s, discuss these maps' implications for the disk regrowth scenario, and comment on extending this work to higher redshift with ALMA.

Tim Weinzirl (University of Texas at Austin)

Shardha Jogee (University of Texas at Austin)
Sadegh Khochfar (Sub-Department of Astrophysics, University of Oxford)
Andi Burkert (Universitats-Sternwarte Munchen)
John Kormendy (University of Texas at Austin)

Constraints on the Assembly and Merger History of Massive Spirals From Their Structural Properties

While major and minor mergers, secular processes, and smooth accretion are known to be relevant galaxy assembly mechanisms, the relative importance and timescales over which they are effective remains debated. We discuss here our results from Weinzirl et al. (2009), where we explore the relative importance of major mergers in the assembly of spiral galaxies and their bulges by comparing our derived structural bulge Sersic index (n) and bulge-to-total ratio (B/T) of massive galaxies with ΛCDM-based hierarchical models of galaxy evolution. We perform 2D bulge-disk-bar decomposition on H-band images of 143 bright, high stellar mass ($\geq 1.0 \times 10^{10} M_\odot$) spirals. We find that a large fraction ($\sim 69\%$) of bright spirals have $B/T < 0.2$, and $\sim 76\%$ have low $n < 2$ bulges. We compare with predictions from a set of hierarchical models where the merger history and input cold gas physics dictates that a spiral has a present-day low $B/T < 0.2$ only if it did not undergo a major merger since $z < 2$. As a result, the predicted fraction ($\sim 1.6\%$) of high mass spirals, which have undergone a major merger since $z < 4$ and host a bulge with a present-day low $B/T < 0.2$ is over 30 times smaller than the observed fraction ($\sim 66\%$) of high mass spirals with $B/T < 0.2$. The results remain similar even in different models where the efficiency of bulge-building during a major merger scales inversely with the cold gas mass fraction. This implies that bulges built via major mergers seriously fail to account for the bulges present in $\sim 66\%$ of high mass spirals, and that most of these bulges are likely to have been built by other processes, such as minor mergers, smooth accretion, and secular processes since $z < 4$. By revealing the detailed distribution and kinematics of the cold gas component in high redshift galaxies, ALMA will enable us to witness these galaxy assembly mechanisms in action and assess their relative importance.

Mark Westmoquette (University College London)

Linda Smith (STScI/ESA)
Jay Gallagher (Univerisity of Wisconsin-Madison)

Spatially-resolved studies of super star cluster feedback in starburst galaxies

Understanding starburst-driven outflows is important for many reasons within the context of galaxy evolution. However, to understand outflows on the large scale, the details of feedback mechanisms from individual star clusters must first be understood. In this talk I will discuss recent results from a number of high spatial and spectral resolution optical integral field spectroscopic studies of the ionized gas environment surrounding super star clusters (SSCs) within local-group starbursts (e.g. NGC 1569, M82, NGC 1140). Through dynamical, excitation and density measurements, these studies are allowing us to build up a picture of (1) how power is fed from these clusters into the surrounding ISM: e.g. we find strong evidence for turbulent mixing layers on the surface of ISM gas clumps created by the interaction of the winds and ionizing photons from the nearby star clusters, and (2) what effects the ISM properties have on how this power is directed: e.g. our spatially resolved maps of the ionized nebular properties have allowed us to examine how the environment changes within a starburst and thus explain differences in the evolutionary path of different SSCs. Our work raises many questions regarding the properties of more embedded and/or cooler gas phases that will be addressed with the IFUs coming online on Herschel and JWST, and with ALMA.

Al Wootten (NRAO)

ALMA's View of the Redshifted Milky Way

We discuss the energy distribution of the Milky Way at high redshift, using NGC 7331 as a local model, in addition to COBE and other observations. The CO J=3-2, J=4-3 and [C II] lines should be detectable at redshifts near z=3 in 24 hour integrations. Other lines may be detectable for otherr redshifts near z=3 which better position those lines in frequency with respect to the atmosphere and ALMA's receivers.

Lihong Yao (University of Toronto)

Evolving Starburst Model of FIR/sub-mm/mm Line Emission and Applications to Nearby Starburst Galaxies

I present a starburst model for FIR/sub-mm/mm line emission of molecular and atomic gas in an evolving starburst region, which is treated as an ensemble of non-interacting hot bubbles which drive spherical shells of swept-up gas into a surrounding uniform gas medium. These bubbles and shells are driven by winds and supernovae within massive star clusters formed during an instantaneous starburst. The underlying stellar radiation from the evolving clusters affects the properties and structure of photodissociation regions in the shells, and hence the spectral energy distributions of the molecular and atomic line emission from these swept-up shells and the associated parent giant molecular clouds contains a signature of the stage evolution of the starburst. By comparing our models with the available observed data of nearby infrared bright galaxies, especially M 82, we constrain the models and in the case of M 82, provide estimates for the age of the recent starburst activity. We also derive the total H_2 gas mass in the measured regions of the central 1 kpc starburst disk of M 82. In addition, we apply the model to represent various stages of starburst evolution in a well known sample of nearby luminous infrared galaxies. In this way, we interpret the relationship between the degree of molecular excitation and ratio of FIR to CO luminosity to possibly reflect different stages of the evolution of star-forming activity within their nuclear regions.

B. Ashley Zauderer (Department of Astronomy, University of Maryland, College Park, MD)

Alberto D. Bolatto, Stuart N. Vogel, Sylvain Veilleux and Peter J. Teuben (Department of Astronomy, University of Maryland, College Park, MD)
James W. Lamb, David P. Woody and Stephen Muchovej (Owens Valley Radio Observatory, California Institute of Technology, Big Pine, CA)
Daniel P. Marrone, Erik M. Leitch and Thomas L. Culverhouse (Department of Astronomy and Astrophysics, University of Chicago, Chicago, IL)
Laura M. Per'ez and John M. Carpenter (Department of Astronomy, California Institute of Technology, Pasadena, CA)
Melvyn C. H. Wright and Richard L. Plambeck (Department of Astronomy, University of California, Berkeley, Berkeley, CA)

High Resolution Imaging of ULIRGs with CARMA

Ultraluminous Infrared Galaxies (ULIRGs) represent a population that is among the most extreme in our universe, emitting an extraordinary amount of energy at infrared wavelengths from dust heated by either prolific star formation and/or the presence of an active galactic nucleus (AGN). There is also strong evidence that the majority of ULIRGs are interacting galaxies or ongoing/recent mergers. There is debate, however, surrounding the intrinsic energy source of many of these highly luminous objects, such as the closest and prototypical ULIRG, Arp 220. We have observed several nearby ULIRGs with CARMA in four configurations, including the longest baseline (up to 2 km) A-array configuration, which has a resolution of $\sim 0.15''$ at 1.3 mm. We have utilized the Paired Antenna Calibration System (PACS) for atmospheric calibration in the longer baseline configurations. In this calibration system, Sunyaev-Zeldovich Array (SZA) antennas were paired with CARMA antennas to allow for a continuous measurement of the atmospheric phase screen on long baselines over time intervals from two seconds to several hours. We performed a variety of tests on bright quasars to confirm the PACS calibration methodology. We present these results along with our scientific results from observations of Arp 220 and other nearby ULIRGs.

Laura Zschaechner (University of New Mexico)

Richard J. Rand (Univ. of New Mexico)
Rene A. M. Walterbos (NMSU)
Robert A. Benjamin (Univ. of Wisconsin-Whitewater)

Kinematics of The Neutral Halo of NGC 4302

It has recently been realized that kinematic measurements of gaseous halos of nearby galaxies may provide important clues to the origin of such halos and thereby the growth and evolution of galaxy disks. In particular, recent measurements have shown a decrease in rotation speed with height in many halos, leading to various models which attempt to understand this gradient in terms of disk-halo flows and accretion of primordial gas. One observational issue is whether ionized and neutral halos show the same kinematics, suggesting a common origin. The most problematically steep gradient, -30 km/s/kpc, has been found in the ionized halo of the Virgo edge-on NGC 4302 by Heald et al. (2007). Here we present deep VLA HI observations of this galaxy. We clearly detect a vertically extended component. We will present models showing whether the kinematics of this component are best represented by a flare, a warp along the line of sight, or a lagging halo.