Oral Abstracts for

Galaxy Evolution Mechanisms

Parallel Session

This Session is sponsored by

nature astronomy

Galaxy Evolution Mechanisms

Tuesday, June 26, 2018

Start	End	Session	Speaker
8:00 AM	9:00 AM	Registration - Grand Ballroom Foyer	
8:45 AM	9:00 AM	Welcome - Grand I	
9:00 AM	10:00 AM	**Plenary: The Formation of Planets in the Terrestrial Zone and Conditions of Habitability**	**Andrea Isella** (B. Matthews, Chair)
10:00 AM	10:20 AM	Poster Flashes - Exoplanets	
10:20 AM	11:00 AM	Break and Posters	
11:00 AM	12:00 PM	**Plenary: The Cosmic Harmony of Galaxies and their Black Holes**	**Alex Pope** (Jackie Hodge, Chair)
12:00 PM	12:20 PM	Poster Flashes - Galaxy Evolution	
12:20 PM	2:00 PM	Lunch	
Galaxy Evolution Mechanisms - Jackie Hodge, Chair			
2:00 PM	2:15 PM	After The Fall: The Dust and Gas in E+A Post-Starburst Galaxies	Adam Smercina
2:15 PM	2:30 PM	Peering Deep in the Radio to Discover the Secrets of Quasar Feedback	Rachael Alexandroff
2:30 PM	2:45 PM	COLDz: The VLA CO Luminosity Density at High Redshift Survey	Ricardo Pavesi
2:45 PM	3:15 PM	**Gastrophysics In Galaxy-Scale Simulations: Peeking Under the Hood**	**Phil Hopkins**
3:20 PM	4:00 PM	Break & Posters	
Galaxy Evolution Mechanisms - Mark Dickinson, Chair			
4:00 PM	4:30 PM	**AGN Near and Far: Clues to Galaxy Evolution from Small to Large Scales**	**Dominika Wylezalek**
4:30 PM	4:45 PM	Synergies Between Large Optical IFU and Interferometric Surveys of Galaxies in the Nearby Universe	Alberto Bolatto
4:45 PM	5:00 PM	Connecting Molecular and Ionized Gas Kinematics to Extraplanar Diffuse Ionized Gas with the EDGE-CALIFA Survey	Rebecca Levy
5:00 PM	5:15 PM	An Overview and First Look at the COSMOS HI Large Extragalactic Survey (CHILES)	Julie Davis
5:15 PM	5:30 PM	Galaxy Mergers Moulding the Circumgalactic Medium	Maan Hani
5:30 PM	6:00 PM	**Exploring Galaxy Formation and Evolution with the Next Generation of Large Optical/IR Telescopes on the Ground**	**Pat McCarthy**
6:00 PM	7:00 PM	Poster Reception	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Andrea Isella (Rice University)

Topic: Exoplanets, the Solar System and the Origins of Stars, Planets and Life

The Formation of Planets in the Terrestrial Zone and Conditions of Habitability

Astronomical observations have revealed thousands of exo-planets including the first exo-planets located in the habitable zone of their host star. Furthermore, observations of young stellar systems at unprecedented angular resolution have delivered images of newborn planetary systems that unveil the physical processes involved in the assembly of planets. Key challenges for the next decade are to characterize the population of planets in the habitable zone, investigate their formation mechanism, understand how they might acquire the key ingredients for life, and assess their capability to sustain life. Addressing these questions requires a multi-disciplinary approach and a substantial advance in the astronomical instrumentation. In my talk, I will present a review of the study of planets in the terrestrial zone and discuss some of the technical capabilities required to unveil the their formation and the conditions of habitability.

Alexandra Pope (University of Massachusetts Amherst)

Topic: Galaxy Evolution Mechanisms

The Cosmic Harmony of Galaxies and their Black Holes

In this talk, I discuss our picture of how galaxies and their supermassive black holes coevolve over cosmic time, especially during the peak, heavily dust-obscured, epoch of galaxy evolution from z~1-4. The past decade has revealed fundamental relationships that govern how galaxies grow through star formation, and become passive. Observations of active black holes in distant galaxies have increased thanks to a multi-wavelength approach, but our precise understanding of how they coevolve with stars over cosmic time remains limited. Future infrared space telescopes such as JWST and, eventually Origins Space Telescope, will concurrently measure the star formation and black hole accretion rates in typical galaxies out to the highest redshifts.

Adam Smercina (University of Michigan)

J.D.T Smith (U. of Toledo), D. A. Dale (U. of Wyoming), K. D. French (Carnegie), K. V. Croxall, S. Zhukovska (MPA), A. Togi (UT San Antonio), E. F. Bell (U. of Michigan) A. F. Crocker (Reed), B. T. Draine (Princeton), T. H. Jarrett (U. of Cape Town), C. Tremonti (UW Madison), Fabian Walter (MPIA), Yujin Yang (KASI), A. I. Zabludoff (U. of Arizona), L. K. Zschaechner (U. of Helsinki)

Topic: Galaxy Evolution Mechanisms

After The Fall: The Dust and Gas in E+A Post-Starburst Galaxies

Recent detections of a significant interstellar medium (ISM) in many post-starburst galaxies challenges their traditional classification as dust- and gas-poor merger remnants, rapidly transitioning to quiescence. We have conducted a multi-wavelength survey of 33 E +A post-starbursts selected from SDSS, including Spitzer, Herschel, and ALMA. We find compact, warm dust reservoirs with high polycyclic aromatic hydrocarbon (PAH) abundances. Their infrared spectral properties are unique, with dominant PAH emission, very weak nebular lines, and deep [C II] deficits – the aging burst populations provide an unusual "high-soft" radiation field that seemingly dominates the post-starbursts' ISM energetics. We also find unusually strong H2 rotational emission, among the brightest, relative to infrared luminosity, of any known galaxy – indicating a highly turbulent ISM. High-resolution ALMA CO(2–1) follow-up observations reveal that the molecular gas in these post-starbursts is exceptionally dense – rivaling the gas found in ULIRGs – and is concentrated in turbulent, rotating nuclear reservoirs. Coupled with modest SFRs from a range of infrared tracers, the post-starbursts' high gas densities indicate highly inefficient star formation – they lie more than an order of magnitude below the Kennicutt-Schmidt star-forming relation. These results paint a coherent picture of systems in which star formation was, indeed, rapidly truncated, but in which the ISM was not completely expelled. High-density nuclear reservoirs of molecular fuel remain but are supported against collapse by some form of continual turbulent heating.

Rachael Alexandroff (Canadian Institute for Theoretical Astrophysics & Dunlap Institute for Astronomy and Astrophysics)

Topic: Galaxy Evolution Mechanisms

Peering Deep in the Radio to Discover the Secrets of Quasar Feedback

Theoretical models of quasar feedback involve radiatively-driven nuclear winds, which propagate into the surrounding interstellar gas (causing shock heating and plowed shells) and resulting in a galaxy-wide wind over the life time of the quasar. There are, however, few observational probes of this particular feedback phenomenon. One relatively unexplored route is to search for the shocked gas in the radio. Though only about 15% of quasars are traditionally "radio-loud", meaning they launch radio jets that can be observed on scales of hundreds of kiloparsecs, we can identify populations of traditionally 'radio-quiet' quasars that produce more radio emission than can be easily explained by just star formation. Indeed, the radio luminosity of powerful radio-quiet and radio- intermediate quasars is correlated with the velocity dispersion of ionized gas (measured via the strong [OIII]λ5007Å emission line), suggesting an intimate connection between radio emission and gas outflows. Recent upgrades to the Karl G. Jansky Very Large Array (VLA) allow for radio observations with unprecedented sensitivity and resolution, opening the radio regime as an additional avenue for studying multi-phase quasar winds and the interaction between quasars and their host galaxies. I will present our recent studies on the radio emission from radio-quiet quasars at both z~0.5 and z~2.5 where we use a combination of radio luminosity, spectral index and morphology in an attempt to disentangle jet- and wind-driven radio emission. In addition, I will present preliminary results from a recent radio survey of z~0.5 quasars with multi-component [OIII] 5007 emission which suggests either the presence of bi-conical outflows or dual supermassive black holes and show how radio data allows us to disentangle these scenarios. Such studies are of increasing importance as we plan for the Next Generation Very Large Array (ngVLA) whose unprecedented resolution and sensitivity will allow us to better disentangle various competing quasar feedback scenarios.

Riccardo Pavesi (Cornell University)

Dominik Riechers (Cornell University)
Chelsea Sharon (McMaster University)
Jacqueline Hodge (Leiden Observatory)
Roberto Decarli (Osservatorio Astronomico di Bologna)
Fabian Walter (Max Planck Institute for Astronomy;Researcher)
Chris Carilli (NRAO)
Emanuele Daddi (CEA)
Ian Smail
Mark Dickinson
Rob Ivison (ESO)

Topic: Galaxy Evolution Mechanisms

COLDz: The VLA CO Luminosity Density at high redshift survey

An understanding of cosmic star formation requires a census of the cold molecular gas that fuels it, especially at the peak epoch of galaxy assembly. A detailed census of cold gas across cosmic time will be one of the major goals for the ngVLA. Here, we set the stage with the Karl G. Jansky VLA - CO Luminosity Density at high-z (COLDz) survey, the first spectral line deep field targeting CO(1-0) emission from galaxies at z~2-3 and CO(2-1) at z~5-7. These low-J CO lines are the most direct tracer of the cold molecular gas in galaxies. Therefore, COLDz provides the most robust constraints to date to the cosmic density of molecular gas at the peak epoch of cosmic star formation and beyond. COLDz covers a 60 times larger area than previous CO deep field studies. By targeting both a wide and a deep field, we provide the first significant constraints to the shape of the CO luminosity function at high redshift. Our line search for CO(1-0) uniformly selects starbursts and massive Main Sequence galaxies based on their cold molecular gas masses, yielding the first CO(1-0) blindly selected sample to date. We find a higher characteristic cold gas mass in galaxies at z~2-3 than predicted by semi-analytical models, as suggested by estimates based on dust emission and higher-J CO lines. Our constraints to the cold gas content of galaxies over the z~2-7 range reproduce the cosmic star formation history for a typical gas depletion timescale of ~0.5 Gyr. Through CO line stacking, we find lower molecular gas mass fractions than expected in faint, Main Sequence galaxies. This legacy survey pushes the current VLA to its limits, demonstrating the potential of cm-wavelength, unbiased CO searches.

Philip F. Hopkins (California Institute of Technology)

Topic: Galaxy Evolution Mechanisms

Gastrophysics In Galaxy-Scale Simulations: Peeking Under the Hood

The most fundamental unsolved problems in star and galaxy formation revolve around "feedback" from massive stars (and black holes). I'll review how new generations of theoretical models combine new numerical methods and physics, to realistically model the diverse physics of the ISM, star formation, and feedback, on a wide range of scales from those of individual proto-stars to the inter-galactic medium. I'll describe how the physics on these incredibly diverse scales is actually governed by many self-similar scaling laws, which emerge naturally owing to the competition between feedback, turbulence, and self-gravity. This provides new understanding of the stellar initial mass function, the reasons why star formation is "clustered" and origins of dense globular clusters, the generation of galactic outflows, and self-regulating star formation in galaxies (the Kennicutt-Schmidt relation and origins of galaxy masses and morphologies). Finally, I'll discuss some of the dominant outstanding mysteries in these areas: the roles of binary stellar evolution and super-massive black hole growth.

Dominika Wylezalek (European Southern Observatory)

Topic: Galaxy Evolution Mechanisms

AGN Near and Far: Clues to Galaxy Evolution from Small to Large Scales

The energy output of actively accreting supermassive black holes (SMBHs) has become a critical ingredient in modern galaxy formation theories. This energy typically exceeds the binding energy of a galaxy, such that even if only a few percent of that energy couples to the gas, gas may be heated and/or driven outside the galaxy which can effectively quench star formation activity.Popular evolution models predict that SMBHs grow initially in obscurity, deep inside a dusty galactic starburst, until a blowout of gas and dust quenches the star formation and reveals a visibly luminous quasar in the galactic nucleus. There is increasing evidence that quasars impact their surrounding gas through winds, which are inhomogeneous, complex multi-phase phenomena, with different gas phases observable in different spectral domains. But constraining the power and reach of such feeding and feedback processes exerted by black holes onto their hosts is a major unresolved issue in modern extragalactic astrophysics.In my talk I will first highlight recent advancements in the field of feeding and feedback of supermassive black holes. I will then show how the next generation of observational facilities can be used to address some of the unanswered questions in the field.

Alberto Bolatto (University of Maryland)

Tony Wong (University of Illinois, Urbana-Champaign)
Leo Blitz (University of California, Berkeley)
Stuart Vogel (University of Maryland, College Park)
Sebastián Sánchez (Universidad Nacional Autónoma de México)
Dyas Utomo (Ohio State University)

Topic: Galaxy Evolution Mechanisms

Synergies Between Large Optical IFU and Interferometric Surveys of Galaxies in the Nearby Universe;Galaxy Evolution Mechanisms

Large scale spectroscopic surveys of galaxies largely neglect their internal structure, which is an integral aspect of their evolution. This is particularly true for molecular gas, for which resolved surveys are costly and samples are small. We used CARMA to image a large galaxy sample based on the CALIFA IFU survey, and exploit the power of combining large sets of spatially and spectrally resolved optical and millimeter-wave data, which remains largely unexplored. I will present results from the EDGE-CALIFA survey, which obtained high-quality CO interferometric observations of 126 CALIFA galaxies. I will discuss local scaling relations between star-formation, molecular, and stellar surface density and their dependence on galaxy mass and local parameters. I will also discuss the statistics for changes in molecular depletion time that occur in galaxy centers, the systematic exploration of the combined stellar, ionized gas, and molecular gas kinematics and their relation with star formation activity. The ngVLA has the potential to take this type of science to the next level: 1) it will have the sensitivity to carry out much faster observations than ALMA, thus enabling sample sizes that will match those of the optical IFU surveys of the future at identical resolution, 2) it will be able to carry out similarly resolved observations for the HI component, which is in most cases the dominant gas reservoir, and 3) it will obtain resolved radio continuum, and also multi-transition molecular data (e.g., CN, CS, HCN, OH), creating an incredibly rich gas dataset with impressive diagnostic power.

Rebecca C. Levy (University of Maryland)

Alberto D. Bolatto (University of Maryland), Peter Teuben (University of Maryland), Sebastián F. Sánchez (Universidad Nacional Autónoma de México), and the EDGE-CALIFA Collaboration

Topic: Galaxy Evolution Mechanisms

Connecting Molecular and Ionized Gas Kinematics to Extraplanar Diffuse Ionized Gas with the EDGE-CALIFA Survey

We present a comparative study of molecular and ionized gas kinematics in nearby galaxies. These results are based on observations from the EDGE survey, which measured spatially resolved $^{12}CO(J=1-0)$ in 126 nearby galaxies. Every galaxy in EDGE has corresponding resolved ionized gas measurements from CALIFA. Using a sub-sample of 17 rotation dominated, star-forming galaxies where precise molecular gas rotation curves could be extracted, we derive CO and Hα rotation curves using the same geometric parameters out to $\gtrsim 1$ R_e. We find that ~75% of our sample galaxies have smaller ionized gas rotation velocities than the molecular gas in the outer part of the rotation curve. In no case is the molecular gas rotation velocity measurably lower than that of the ionized gas. We suggest that the lower rotation velocity of the ionized gas can be attributed to a significant contribution from extraplanar diffuse ionized gas in a thick, turbulent disk. Observed line ratios tracing diffuse ionized gas are elevated compared to typical values in the midplane of the Milky Way. Kinematic simulations show that a thick disk with a vertical rotation velocity gradient can reproduce the observed differences between the CO and Hα rotation velocities (Levy et al. 2018). Using a sub-sample of edge-on disk galaxies in the EDGE-CALIFA survey, we report preliminary measurements of ionized gas scale heights and vertical rotation velocity gradients. In galaxies affected by this phenomenon, dynamical masses measured using ionized gas rotation curves will be systematically underestimated. This effect will be especially important at high redshifts. Further study of the connection among the kinematics of various ISM phases, stellar feedback, and galaxy dynamics requires high spatial and spectral resolution observations over a range of galaxy properties and redshifts. This field is ready for study with ALMA, the VLA, and the next generation of optical/infrared telescopes and IFUs (e.g. MUSE, SAMI, MIRI).

Julie Davis (University of Wisconsin-Madison)

Julia Gross (Columbia University) + The CHILES Collaboration

Topic: Galaxy Evolution Mechanisms

An Overview and First Look at the COSMOS HI Large Extragalactic Survey (CHILES)

An enduring question in galaxy evolution concerns how galaxies obtain cold gas--the fuel for ongoing star formation. To address this question, we present the COSMOS HI Large Extragalactic Survey (CHILES), a project currently underway on the Jansky Very Large Array (VLA). The CHILES collaboration has been granted 1000 hours of B-array observing time to image neutral hydrogen (HI) in a 30’ x 30’ cone centered on the COSMOS field and covering a redshift range of z = 0 to z = 0.45. CHILES anticipates HI detection of ~ 300 galaxies through previously unprobed intermediate redshifts, with sensitivity and angular resolution similar to and thus useful for comparison with Square Kilometer Array pathfinder projects. We present here an overview of the survey and a preliminary look at ongoing science with the first 400 hours of data.

Maan Hani (University of Victoria)

Martin Sparre (Universität Potsdam, AIP)
Sara Ellison (University of Victoria)
Paul Torrey (MIT)
Mark Vogelsberger (MIT)

Topic: Galaxy Evolution Mechanisms

Galaxy Mergers Moulding the Circumgalactic Medium

Galaxy evolution is primarily driven by the life cycle of gas. The circumgalactic medium (CGM) is a key part in this cycle, viz. the CGM is a major gas reservoir where inflowing cold gas mixes with outflowing metal enhanced gas and ultimately settles onto the interstellar medium. Galaxy-galaxy mergers have been hypothesized to play a critical role in shaping the CGM's chemical and physical structure. In addition to being a fundamental evolutionary path for galaxies to grow their stellar mass and trigger star formation and AGN activity, galaxy mergers are known to vigorously reshuffle the gas reservoir due to strong tidal torques and feedback processes which are induced by the interaction. However, detailed predictions for the effect of galaxy mergers on the CGM are currently lacking. In this talk, I will present a new analysis of the CGM of major mergers using cosmological zoom-in hydrodynamical simulations. This analysis provides the first constraints on the interplay between mergers and the CGM in a self-consistent cosmological framework. I will demonstrate the long lasting effects of mergers on the metal content of the CGM and its ionization, specifically highlighting the importance of mergers in moulding the CGM of galaxies: increasing its metal content by factors of 2-3, preferentially increasing the covering fractions of the high ionization species, and the large radial extent of such enhancements. Finally, I will use these simulations to make predictions of absorption line column densities and metal distributions in the CGM of post-merger galaxies, that can be directly tested with observations (i.e. with HST-COS).

Patrick J. McCarthy (Carnegie Institution and the Giant Magellan Telescope Organization)

Topic: Galaxy Evolution Mechanisms

Exploring Galaxy Formation and Evolution with the Next Generation of Large Optical/IR Telescopes on the Ground.

The coming generation of giant telescopes working from the atmospheric UV cutoff to the mid-IR will bring new capabilities to the study of galaxy formation and evolution. I will discuss the potential of the large increases in collecting area and angular resolution offered by these telescope to the study of first light and reionization, galaxy dynamics at cosmic noon, the chemical evolution of galaxies and galaxy-gas interactions. Observations of high redshift galaxies are photon-starved and as we continue to dissect galaxies into finer spatial and velocity intervals the need for additional collecting area is becoming acute. The advent of near- and mid-IR optimized space telescopes and deep wide-field surveys from both space and the ground will provide large and complete samples of rare objects. Centimeter to sub-mm wave instruments are providing us with a new window on gas in distant galaxies. I will discuss how all of these tools, and the large optical telescopes in particular, can be used to address key questions in galaxy formation and evolution.

Galaxy Evolution Mechanisms
Wednesday, June 27, 2018

Start	End	Session	Speaker
9:00 AM	10:00 AM	**Plenary: Stellar Mass and Supermassive Black Holes in Era of Multi-Messenger Astronomy**	**Sebastian Heinz** (Joe Lazio, Chair)
10:00 AM	10:20 AM	Poster Flashes - Black Holes	
10:20 AM	11:00 AM	Break and Posters	
11:00 AM	12:00 PM	**Plenary: The Evolution of Astrochemistry from Planet Formation Through to Exoplanets**	**Ilse Cleeves** (Laura Fissel, Chair)
12:00 PM	12:20 PM	Poster Flashes - Galaxy Evolution	
12:20 PM	12:30 PM	Conference Photo	
12:30 PM	2:00 PM	Lunch	
Galaxy Evolution Mechanisms - Karin Sandstrom, Chair			
2:00 PM	2:30 PM	**Extreme Star Forming Environments in Nearby Galaxies**	**Jean Turner**
2:30 PM	2:45 PM	Constraining Metal Mixing and Feedback Using Spatially Resolved Metal Production Histories in M31	Grace Telford
2:45 PM	3:00 PM	The IGM and Galaxy Evolution in Galaxy Groups	Eric Wilcots
3:00 PM	3:15 PM	Super Star Cluster Formation and Evolution with ALMA	Michelle Consiglio
3:20 PM	4:00 PM	Break & Posters	
Galaxy Evolution Mechanisms - Alex Pope, Chair			
4:00 PM	4:30 PM	**Dynamics of High-redshift Gas-rich Galaxies**	**Jackie Hodge**
4:30 PM	4:45 PM	Understanding Galaxies Formation at the Reionization Epoch	Xiangcheng Ma
4:45 PM	5:00 PM	Molecular Universe on Large Scales: Revealing the Cold Baryon Cycle That Drives Galaxy Evolution with the Next-Generation Radio Telescopes	Bjorn Emonts
5:00 PM	5:15 PM	Study of Heavily Obscured Quasars with Young Radio Jets at Redshifts, z ~2	Pallavi Patil
5:15 PM	5:45 PM	**Far-IR Mysteries**	**Allison Kirkpatrick**
5:45 PM	6:00 PM	*Short Spacing Configurations for Full Flux Recovery with the ngVLA*	*Peter Teuben*

Bold = Invited Speaker
Italics = ngVLA Community Studies Talk

Sebastian Heinz (UW-Madison)

Topic: Black Holes & Transient Phenomena

Stellar Mass and Supermassive Black Holes in Era of Multi-Messenger Astronomy

I will discuss the future of multi-wavelength studies of the growth history of black holes at all mass scales over the coming decades. Just as numerical modeling of accretion and ejection phenomena approach an ab-initio understanding of the innermost regions of black hole atmospheres, the next generation of radio and X-ray telescopes will allow an unprecedented view of non-thermal phenomena that holds the keys to understanding some of the mysteries of black hole growth that have plagued black hole studies for that past five decades. My discussion will be motivated by a modern 3D MHD numerical view into black hole atmospheres.

Ilse Cleeves (Harvard-Smithsonian CfA)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Evolution of Astrochemistry from Planet Formation Through to Exoplanets

Protoplanetary disks are the birthplaces of planetary systems. Studying their physical conditions and compositions provides constraints on how planets form and with what chemical make up: whether they are rocky or gas-rich, whether their atmospheres are carbon or oxygen rich, and so forth. In recent years the unprecedented sensitivity of ALMA has demonstrated a rich diversity in observed molecular emission strength and emitting geometries, hinting at an active disk chemistry during planet formation even for simple molecules. Going forward, we need to understand what the main evolutionary drivers are of this active chemistry (for example, the coupling of ice coated grains and grain growth), and if what we learn for well-studied bright/massive/nearby objects holds for the broader population of disks. Together these explorations will compliment and motivate our understanding of the march toward chemical complexity in disks, where the future highly sensitive ngVLA will shed light on the richer, and potentially prebiotic, organic chemistry of disks.

Jean Turner (University of California, Los Angeles)

Topic: Galaxy Evolution Mechanisms

Extreme Star Formation

New telescopes capable of observing light at the shortest microwave wavelengths, in the submillimeter and millimeter portions of the spectrum, at arcsecond or subarcsecond resolutions, offer views of extreme kinds of star formation not found in the Galaxy. These observations are giving us new understanding of the most massive stars, massive star clusters, how they form and their feedback and relation to galaxy formation. Centimeter wavelengths have much to offer in this arena, especially with the improvements in sensitivity, imaging fidelity, and resolution that would be offered by the ngVLA. This talk focuses on the questions that are being raised by recent observations of extreme star formation in the local universe.

Grace Telford (University of Washington)

Jessica Werk (University of Washington)
Julianne Dalcanton (University of Washington)

Topic: Galaxy Evolution Mechanisms

Constraining Metal Mixing and Feedback Using Spatially Resolved Metal Production Histories in M31

A comprehensive theory describing how the energetic feedback and metal production due to star formation affect the evolution of entire galaxies is an important goal for the coming decades. A promising way forward is to connect spatially and temporally resolved star formation histories (SFHs) to the evolution of global ISM properties within galaxies. The SFH is tightly coupled to the history of metal production within a galaxy via ejective feedback from both young and evolved stellar populations. Therefore, given knowledge of the spatially resolved metal production history and the present-day distribution of metals in a galaxy disk, metals can be leveraged as tracer particles to constrain the necessary feedback due to star formation over the galaxy's history. M31 is a unique case in which the necessary data to make such measurements are available. The ancient SFHs within ~kpc sized regions have been derived in M31 from color-magnitude diagrams of resolved stars from the Panchromatic Hubble Andromeda Treasury survey (Williams et al. 2017). In this talk, we use these CMD-based SFHs to calculate spatially resolved histories of metal production in M31. We model when and where Type II SNe, Type Ia SNe, and AGB stars inject O, C, N, and Fe into the ISM. We calculate the total metal mass formed up to the present as a function of radius, predicting the spatial distribution of metals if metals remain in the location where they formed. But if metals are transported within the disk (via turbulent mixing) and/or ejected into the gaseous halo and possibly re-accreted (via SN feedback, galactic fountain), then the distribution of metals will change. We compare our predicted radial metal gradient for the case of no metal transport to the metal gradient inferred from observations of the stars, gas, and dust in M31. This assessment of global metal mixing in a galaxy disk provides a unique test of the required feedback from low-level star formation over several Gyr timescales.

Eric Wilcots (University of Wisconsin)

Topic: Galaxy Evolution Mechanisms

The IGM and Galaxy Evolution in Galaxy Groups

We now understand that a significant amount, if not most, of the baryonic matter in the Universe resides in what is broadly considered to be the intergalactic medium (IGM). It is also becoming increasingly evident that this gas can have a profound impact on the evolution of galaxies in groups. While some of this matter likely exists in the immediate environment of individual galaxies in what is known as the circumgalactic medium (CGM), much of it is thought to fill a ""cosmic web"" that forms the large-scale structure of the Universe. Given that a large portion of the CGM and IGM is very diffuse and thus difficult to measure in emission at any wavelength, many observational studies have focused primarily on detecting this gas in absorption, using absorption lines of a variety of ions to probe different gas regimes in the ultraviolet part of the spectrum. We are taking a different approach, probing this important component of the baryonic content of the Universe using radio telescopes. In this talk I will show how we can use radio galaxies to measure the baryon content of the intergalactic medium to account for the missing baryons in these systems and what impact this gas may have on the evolution of resident galaxies. We are also using deep radio continuum observations to detect the presence of large-scale intergalactic magnetic fields, particularly in the group environment. Lastly, I will discuss how the new generation of radio observations with sufficiently long integration times and high sensitivities offer the ability to probe neutral hydrogen in absorption in the intergalactic medium.

S. Michelle Consiglio (UCLA)

Jean Turner (UCLA)

Topic: Galaxy Evolution Mechanisms

Super Star Cluster Formation and Evolution with ALMA

ALMA has significantly increased our knowledge about the formation and evolution of super star clusters (SSCs), the most massive clusters with $M > 10^5$ M_{sun}. Potentially very different in evolution and feedback than less massive clusters, SSCs seem to form more efficiently than Galactic star-forming regions. SSCs may significantly enrich their surrounding clouds, to solar or super-solar metallicities in the span of only a few Megayears. Mechanical feedback may be subdued in some of these young SSCs, and has been predicted theoretically. Additionally, the formation of the large clusters may be fueled by infalling filaments of circumgalactic gas. We present ALMA observations of forming SSCs in two local dwarf galaxies, II Zw 40 and NGC 5253, that present many new questions about this mode of star formation.

Jacqueline Hodge (Leiden University)

Gabriela Calistro Rivera (Leiden University), Matus Rybak (Leiden University), & the ALESS collaboration

Topic: Galaxy Evolution Mechanisms

Dynamics of High-redshift Gas-rich Galaxies

Dynamical studies of the gas reservoirs in high-redshift galaxies can provide valuable insight into the total mass in the different components within the galaxies (e.g., gas, stars, dark matter) as well as the nature of the galaxies themselves (e.g., mergers vs. disks). Historically, the angular resolution and signal-to-noise required to carry out such studies in the distant (z>1) universe have been very challenging to obtain. However, with the advent of ALMA, these observations are becoming increasingly possible. I will present recent work with ALMA on the dynamics of gas-rich submillimeter galaxies traced by carbon monoxide (CO), including a Bayesian approach to investigate the uncertainties inherent to dynamically constraining total gas masses. I will also discuss dynamical studies utilizing the 158um fine-structure line of singly-ionized carbon ([CII]), including a comparison of dynamical tracers and implications at the highest redshifts. I will end with a discussion of future prospects for dynamical studies of high-z galaxies with current & upcoming facilities.

Xiangcheng Ma (California Institute of Technology)

Topic: Galaxy Evolution Mechanisms

Understanding Galaxies Formation at the Reionization Epoch

Understanding the properties of galaxies at $z > 5$ and their contribution to cosmic reionization is one of the most important questions in astronomy to be answered in the next decade, given the fact that there will be a large amount of new data coming out soon (e.g., from the James Webb Space Telescope). We will present a new suite of high-resolution cosmological zoom-in simulations of $z > 5$ galaxies, taking advantage of the realistic treatments of the multi-phase ISM, star formation, and stellar feedback from the Feedback in Realistic Environment (FIRE) project. These simulations are among the most detailed $z > 5$ galaxy simulations to date and can be very useful for predicting and understanding future observations. We will show some first results from our simulations, including the morphologies and sizes of $z > 5$ galaxies and their implications for Frontier Fields observations, Lyman-alpha profile and strength and their correlation with Lyman-continuum escape fraction, and dust extinction, temperature, and IR luminosities in high-redshift galaxies.

Bjorn Emonts (NRAO)

Galaxy Evolution Mechanisms

The Molecular Universe on Large Scales: Revealing the Cold Baryon Cycle That Drives Galaxy Evolution with the Next-Generation Radio Telescopes

The evolution of galaxies is tightly linked to processes that occur in the circum-galactic medium (CGM). Unfortunately, most of the baryons in the CGM are too faint to be easily detected. At high-z, we view glimpses of dark baryonic halos through quasar absorption lines, or cooling-radiation emitted as Lyα. However, a direct connection to the stellar growth of massive galaxies remains missing, because we have yet to identify the ultimate reservoir of halo gas that has sufficient mass to fuel widespread star-formation, namely the cold molecular gas (~10-100 K). Using sensitive low-surface-brightness observations of carbon-monoxide (CO) and atomic carbon ([CI]), we discovered extended molecular gas reservoirs in the halo environments of several massive high-z radio galaxies. In the case of the Spiderweb Galaxy, located in a protocluster at z=2, this cold CGM fuels in-situ star formation across the 100 kpc-scale halo, and has a carbon abundance and excitation conditions similar to the ISM in starforming galaxies. These results imply that massive high-z galaxies grown not directly through accretion of pristine gas from the Cosmic Web, but from recycled gas in the CGM. I will explain the technical challenges involved in lighting up these hitherto hidden reservoirs of cold molecular CGM, and show how low-surface-brightness observations with future facilities, in particular ALMA Band-1 and the core of the Next-Generation VLA, promise to revolutionize our view of the molecular Universe.

Pallavi Patil (University of Virginia/National Radio Astronomy Observatory)

Carol Lonsdale (National Radio Astronomy Observatory)
Mark Whittle (University of Virginia)
Kristina Nyland (National Radio Astronomy Observatory)
Mark Lacy (National Radio Astronomy Observatory)

Topic: Galaxy Evolution Mechanisms

Study of Heavily Obscured Quasars with Young Radio Jets at Redshifts, z ~2.

The active galactic nucleus (AGN) phenomenon, driven by accretion onto supermassive black holes, influences the formation and subsequent evolution of galaxies and their constituent stars, gas, and dust via radiative and mechanical energy transfer (termed AGN feedback) to the surrounding interstellar and intergalactic media. Dust obscured quasars are likely going through early stages of feedback due to recent triggering of AGN activity. Thus, they are ideal for studying such interactions. We present high-resolution Jansky Very Large Array (JVLA) imaging of 156 hyper-luminous and heavily obscured quasars found at redshifts z ~ 0.4-3. These galaxies were selected to have extremely red MIR-optical colors in WISE and bright, compact radio emission in NVSS/FIRST. JVLA snapshot observations at 10GHz with sub-arcsecond-scale angular resolution revealed that 115 out of 156 sources are indeed compact, radio-loud, and have structures on scales ≤ 2 kpc (at z~2). We performed a detailed analysis of the radio SEDs of our sample sources. A few sources have peaked radio spectra, and thus belong to the class of young radio AGNs (e.g. High Frequency Peakers (HFP), Gigahertz Peaked Spectrum (GPS) and Compact Steep Spectrum (CSS) radio sources). This suggests that the radio jets could be recently (re)triggered and are clearing their way out of the dense ISM of the host. The next generation Very Large Array (ngVLA) is an ideal instrument to probe the sub-galactic jet extents in our sample sources. The unique combination of high angular resolution, large collecting area, and broad frequency range will enable us to perform a spatially resolved study of the compact radio jets and constrain their ages. We also discuss the implications of this study for our understanding of the impact of young jets on the evolution of the host galaxy.

Allison Kirkpatrick (Yale University)

Chelsea Sharon (McMaster University)
Alexandra Pope (University of Massachusetts Amherst)

Topic: Galaxy Evolution Mechanisms

Far-IR Mysteries

In this talk, I will highlight what we know about far-IR emission at cosmic noon, when most of the star formation and black hole growth occurred behind thick screens of dust. At z=1-2, star forming galaxies are colder than their local counterparts, and they have an order of magnitude more dust than local galaxies of the same stellar mass. They are also more extended in their gas disks, although the true extent of the dusty interstellar medium is unknown. In addition many of these galaxies are harboring a hidden active galactic nucleus. This accreting supermassive black hole may be having an effect on the far-IR emission, including the cold molecular gas, which I will demonstrate through an analysis of CO spectral line energy distribution. I talk about open questions in the field and how future telescopes, particularly the Origins Space Telescope, can answer them.

Galaxy Evolution Mechanisms
Thursday, June 28, 2018

Start	End	Session	Speaker
9:00 AM	12:20 PM	Working Groups/Free Time	
12:20 PM	2:00 PM	Lunch	
2:00 PM	3:00 PM	**Plenary: Pulsars in the Galactic Center as Fundamental Tests of Gravity**	**Dimitrios Psaltis** (Walter Brisken, Chair)
3:00 PM	3:20 PM	Poster Flashes - Black Holes	
3:20 PM	4:00 PM	Break and Posters	
Galaxy Evolution Mechanisms - Fabian Walter, Chair			
4:00 PM	4:30 PM	**The Coevolution of Galaxies and their Supermassive Black Holes**	**Anne Medling**
4:30 PM	4:45 PM	Witnessing the Growth of Massive Black Holes at Cosmic Dawn and Noon With JVLA and ALMA	Wiphu Rujopakarn
4:45 PM	5:00 PM	The Early Stage of Cluster Formation Caught in a Massive Protocluster at z=3.78	Kyoung-Soo Lee
5:00 PM	5:15 PM	Investigating Dark Matter Substructure in Massive Galaxies w/Strong Gravitational Lensing	Chris Fassnacht
5:15 PM	5:30 PM	Resolving a Fast Molecular Outflow From a Dusty Star-forming Galaxy at z=5.3	Justin Spilker
5:30 PM	6:00 pm	**Luminous Infrared Galaxy Studies with Next Generation Telescopes**	**Aaron Evans**

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Dimitrios Psaltis (University of Arizona)

Topic: Black Holes and Transient Phenomena

Testing General Relativity with the Event Horizon Telescope, Pulsars, and Stars around Sgr A*

The Event Horizon Telescope is a mm VLBI array that commenced its full array operations in April 2017. Its primary goal is to generate the first images of black holes with horizon-scale resolution for the two primary targets, Sgr A* in the center of the Milky Way and the black hole in the center of M87. Measuring the shape and size of the shadows cast by the black holes allows for testing the no-hair theorem of General Relativity and for searching for large-scale quantum fluctuations of the black-hole metrics. In the case of Sgr A*, tests with the Event Horizon Telescope can be combined with monitoring of orbits of stars and pulsars in its vicinity to provide consistency checks and further constraints on any deviations from General Relativity.

Peter Teuben (University of Maryland, College Park)

Jordan Turner (University of Wyoming)
Daniel Dale (University of Wyoming)

Topic: Galaxy Evolution Mechanisms

Short Spacing Configurations for Full Flux Recovery with the *ngVLA*

The next generation *Very Large Array* will provide unprecedented resolution and sensitivity at radio frequencies from 1 to 115 GHz. Like any interferometric array, the *ngVLA* will not cover all possible baselines and thus it will be limited in its ability to recover the true flux for all observed spatial scales.

We present a detailed study of simulations carried out by adding various short spacing antennae configurations (large single-dish and closely packed compact array) to the interferometric data. We discuss the benefits of the short spacing configurations for mapping Milky Way extended emission, nearby galaxies, and probing high-dynamic range fields. The simulations make use of the Quick Array Combinations (QAC) CASA add-on derived from the TP2VIS project.

Anne Medling (Caltech)

Topic: Galaxy Evolution Mechanisms

The Coevolution of Galaxies and their Supermassive Black Holes

The evolution of supermassive black holes and their host galaxies are intertwined, whether by a feedback loop, in which the growth of one limits the fueling of the other, or by a simple coincidence of physical processes affecting both systems. I will give an overview of the current observational constraints on black hole growth and active galactic nucleus (AGN) feedback from world-class observatories such as *Keck/VLT*, *HST*, and *ALMA*. AGN-driven winds have been observed in multiple wavelength regimes, confirming that this feedback can couple to multiple phases of the interstellar medium (ISM): ionized, neutral, and molecular gas. However, most examples of outflows in different phases also trace different spatial scales in disjoint samples of galaxies. The next step to understanding how AGN feedback affects its host galaxy (and does or does not limit star formation) will come from spatially-matched high resolution observations of nearby AGN that trace the ISM in its different phases. Today's newest and upcoming facilities are poised to provide this comparison, and will provide key constraints on the physical prescriptions used in galaxy evolution simulations.

Wiphu Rujopakarn (Chulalongkorn University)

Topic: Galaxy Evolution Mechanism

Witnessing the growth of massive black holes at Cosmic Dawn and Noon with the JVLA and ALMA

We present two areas of results that demonstrate the unique complementarity of some of the most sensitive centimetric and sub/millimeter surveys from the JVLA and ALMA to date to study the formation and growth of supermassive black hole (SMBH) since Cosmic Dawn.

First, the growth of typical SMBHs at redshift > 5, which is key to understanding the origin of the SMBH--bulge relations and the role of active galactic nucleus (AGN) in reionizing the intergalactic medium, is currently beyond the capability of X-ray, infrared, and optical identifications. All spectroscopically-confirmed AGNs at redshift > 5 to date are limited to luminous quasars at the massive end of the SMBH mass function. Our team has conducted a sensitive 6 GHz JVLA survey of the Hubble Ultra-Deep Field (HUDF), revealing that 1% of 5-sigma sources have absolutely no counterparts in any other bands. To evade detection in a field with extremely sensitive optical and infrared observations such as the HUDF, they almost certainly have to be at high redshift, implying radio powers in the range of AGNs. Sensitive ALMA survey of the HUDF further securely excludes the possibility of them being high-redshift star-forming galaxies. We present these AGN candidates and discuss the ongoing efforts to characterize this potentially new AGN population using the *JWST* NIRCam and MIRI GTO surveys of the HUDF.

Second, we present a new technique that combines the JVLA and ALMA observations to localize the sites of SMBH growth in AGNs at redshift ~ 3 in relation to the regions of intense star formation in their hosts down to sub-kiloparsec accuracy. These AGNs are selected from the JVLA and ALMA observations in the HUDF and COSMOS, with the centimetric radio emission tracing both star formation and AGN, and the sub/millimeter emission by dust tracing nearly pure star formation. By requiring the radio emission to be far more luminous than the level associated with the sub/millimeter star formation, we can ensure that the radio emission is AGN-dominated, thereby allowing localization of the AGN and star formation independently. In all three pilot galaxies, the AGNs are located within the compact regions of gas-rich, heavily obscured, intense nuclear star formation, with R_e = 0.4–1.1 kpc and star formation rates of 100–1,200 solar masses per year. If the current episode of star formation continues at such a rate over the stellar mass doubling time of their hosts, ~0.2 Gyr, the newly formed stellar mass will be of the order of 10^{11} solar masses within the central kiloparsec region, concurrently and co-spatially with significant growth of the SMBH. This is consistent with a picture of *in situ* galactic bulge and SMBH growth, and may represent the dominant process regulating the bulge--SMBH relationship through which all massive galaxies may pass. However, the duty cycle may be so short that relatively few examples are found in deep fields thus far. We will discuss the future synergies between VLA, ALMA, and *JWST* to study the *in situ* coevolution scenario.

Kyoung-Soo Lee (Purdue University)

Topic: Galaxy Evolution Mechanisms

The Early Stage of Cluster Formation Caught in a Massive Protocluster at z=3.78

The formation and evolution of galaxies are profoundly influenced by their local environment. The redshift evolution of the cluster red sequence and the properties of cluster ellipticals support a scenario of early accelerated formation followed by swift quenching, placing their formation epoch at z=2-4. However, the details of how and when the local environment influenced cluster galaxies remains unconstrained. In order to understand causality, we must rewind the clock and study galaxies at a time when the massive cosmic structures were coming together. I will summarize new results on a massive protocluster at z=3.78 with currently 52 confirmed galaxy members including a major-merger system. High overdensities are found in all types of galaxies probed in the study, including massive passively evolving galaxies. The angular and redshift distribution of galaxy constituents hint at the complex nature of its dynamical state, where multiple galaxy groups are coming together; when it coalesces into a galaxy cluster, the total mass will exceed that of the Coma cluster (>2x10^15 Msun). The prevalence of ultramassive quiescent galaxies as early as z~3.8 pushes further back the formation epoch in which cluster red sequence was first established. Identification of a large and diverse population of galaxies residing in a bona fide super-Coma progenitor paves a way for upcoming facilities such as JWST to elucidate the key physical processes shaping the formation of cluster galaxies in exquisite detail.

Chris Fassnacht (UC Davis)

John McKean (ASTRON / Groningen)
Simona Vegetti (MPA)

Topic: Galaxy Evolution Mechanisms

Investigating Dark Matter Substructure in Massive Galaxies with Strong Gravitational Lensing

Numerical simulations of galaxy formation within the cold dark matter paradigm generically find that galaxies are surrounded by thousands of subhalos (substructure). However, the number of known Milky Way satellites is significantly smaller than that predicted by the simulations; a situation known as the Missing Satellites problem. One explanation for the discrepancy between theory and observations is that the subhalos are present, but are not luminous enough to be detected, due to astrophysical processes. However, a second intriguing possibility is that our model for dark matter is incorrect. If, for example, dark matter is mildly relativistic ("warm"), the particles would be able to escape from the gravitational potential of low-mass subhalos, effectively erasing substructure below a certain mass range. In order to distinguish between these possibilities, we need a technique that can detect subhalos even if they are purely dark. Gravitational lensing provides perhaps our best method for doing this, since the lensing signature depends only on the mass of the lensing objects and not on whether they are luminous or not. In the "gravitational imaging" technique, small perturbations to strongly lensed arcs or Einstein rings can reveal the presence of small halos either in the halo of the primary lensing galaxy or along the line of sight. The comparison of the statistics of detected halos with the predictions of the models can thus provide critical information on the nature of dark matter.

The divergence between the various models of dark matter is most pronounced at low masses (below 10^8 M_{sun}). Therefore, the lensing technique has its strongest distinguishing power if the limiting mass that can be detected is as low as possible. One of the key ingredients in pushing to a lower-mass detection limit is the angular resolution of the observations. The planned extremely large telescope facilities (TMT, GMT, E-ELT) and the Next Generation VLA will, thus, provide an extremely promising path toward an understanding of the nature of dark matter.

Justin Spilker (University of Texas at Austin)

The SPT SMG Collaboration

Topic: Galaxy Evolution Mechanisms

Resolving a Fast Molecular Outflow From a Dusty Star-forming Galaxy at z=5.3

Galaxies have long been known to grow inefficiently, with only a few percent of the available gas converted into stars each dynamical time. This is typically attributed to feedback processes that regulate the growth of stellar mass. Outflowing winds driven by radiation pressure, supernovae or supermassive black hole accretion are one such process, and can act to halt star formation if they heat, disrupt, or expel the gas supply. We have discovered a fast-moving molecular outflow launched from a dust-rich star-forming galaxy observed when the universe was only one billion years old, and spatially resolve the wind on sub-kiloparsec scales. The wind reaches velocities up to 800 km/s relative to the galaxy, covers a high fraction of the face of the source, and carries mass at a rate comparable to the star formation rate. Our results show that molecular outflows can suppress the rapid star formation that typifies dusty galaxies at high redshift on short timescales.

Aaron Evans (University of Virginia / NRAO)

The GOALS Team

Topic: Galaxy Evolution Mechanisms

Luminous Infrared Galaxy Studies with Next Generation Telescopes

The availability of ground and space-based telescopes collectively covering much of the electromagnetic spectrum have enabled exciting multi-wavelength views of luminous infrared galaxies in the local Universe. These galaxies are powered by interaction and merger-induced star formation and AGN activity, and there is growing evidence of feedback which likely plays a role in regulating the fueling of both phenomena. In this talk, I will motivate the need for the increase in sensitivity and resolution delivered by the next generation of telescopes, especially those at radio to FIR wavelengths, to diagnose the physical processes at work in these extreme starburst systems at the scales of 10s of parsecs.

Galaxy Evolution Mechanisms

Friday, June 29, 2018

Start	End	Session	Speaker
9:00 AM	10:00 AM	**Plenary: Connecting Interstellar Gas and Star Formation in Nearby Galaxies**	**Karin Sandstrom** (Aaron Evans, Chair)
10:00 AM	10:40 AM	Break and Posters	
Galaxy Evolution Mechanisms - Aaron Evans, Chair			
10:40 AM	11:10 AM	**Galaxy Evolution in the Early Universe**	**Steve Finkelstein**
11:10 AM	11:25 AM	Galaxy Spin Build-Up in the Cosmic Web in the Era of Integral Field Spectroscopy	Charlotte Welker
11:25 AM	11:40 AM	Flat Rotation Curve of Disk Galaxy, DSFG850.95 at z ~ 1.6	Patrick Drew
11:40 AM	11:55 AM	Results from a CO Line Search in the Plateau de Bure High-z Blue Sequence Survey Data	Laura Lenkic
12:00 PM	1:40 PM	Lunch	
Galaxy Evolution Mechanisms - Alberto Bolatto, Chair			
1:40 PM	2:10 PM	**Evolution of Gas Content Through Cosmic History**	**Fabian Walter**
2:10 PM	2:25 PM	*Uncovering the Impact of Jet-ISM Feedback on Galaxy Evolution in the ngVLA Era*	*Kristina Nyland*
2:25 PM	2:40 PM	Extreme Feedback in AGN-Starburst Systems: Insight from Multi-Faceted Molecular Gas Studies	Avani Gowardhan
2:40 PM	2:55 PM	ALMA Twenty-Six Arcmin2 Survey of GOODS-S at One-millimeter (ASAGAO): Physical Properties of ALMA-selected Galaxies	Yuki Yamaguchi
2:55 PM	3:10 PM	A New Detection of Extragalactic Anomalous Microwave Emission in a Compact, Optically-Faint Region of NGC 4725	Eric Murphy
3:20 PM	4:00 PM	Break & Posters	
4:00 PM	5:00 PM	Summary and Final Remarks	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Karin Sandstrom (University of California, San Diego)

Topic: Galaxy Evolution Mechanisms

Connecting Interstellar Gas and Star Formation in Nearby Galaxies

Star formation on galactic scales is governed by the need to collect interstellar gas into successively denser and colder phases, beginning with the accretion of low density gas from the circumgalactic medium all the way through the collapse of dense protostellar cores in molecular clouds. How effectively gas can proceed through these changes in its chemical and physical state depends on the local environment and therefore can vary within and between galaxies. Nearby galaxies are our best laboratory for studying these processes, providing an external, galaxy-wide perspective on the structure and properties of ISM gas. I will discuss our current observational constraints on the key phase transitions that govern the state of gas in nearby galaxies. In particular, I will discuss the properties of the cold neutral gas, the balance between neutral and molecular gas phases, and the density structure of molecular clouds and its relation to star formation. Key aspects of the physics of ISM gas in nearby galaxies remain out of the reach of current observational facilities and I will outline how future observations with the ngVLA, the SKA, and the Origins Space Telescope will revolutionize our understanding of the physics of ISM gas and star formation in nearby galaxies.

Steven Finkelstein (UT Austin)

Topic: Galaxy Evolution Mechanisms

Galaxy Evolution in the Early Universe

The past decade has seen a remarkable growth in our knowledge about galaxy formation and evolution in the distant universe. While this has mostly been driven by the Hubble Space Telescope, the physical insights we gain into these galaxies increasingly requires a multi-wavelength perspective. I will discuss recent highlights from this era in the universe, and share how Hubble, teamed up with ALMA, Spitzer, Chandra and other facilities has illuminating this interesting epoch. I will then discuss how the next generation of facilities, both ground and space-based, will continue this growth into the future.

Charlotte Welker (University of Western Australia)

Joss Bland-Hawthorn (Usyd), Chris Power (UWA), Christophe Pichon (IAP), Yohan Dubois (IAP)

Topic: Galaxy Evolution Mechanisms

Galaxy Spin Build-Up in the Cosmic Web in the Era of Integral Field Spectroscopy

In this talk, I will use a synergy between hydrodynamic simulations and IFS data to review the deep connection between the build-up of galactic angular momentum and cosmic flows shaped by the cosmic web on Megaparsec scales, at different stages of galaxy evolution. Using the state-of-the-art cosmological hydrodynamic simulation Horizon-AGN and IFS mocks tailored to the SAMI IFS survey, I will in particular highlight the importance of the hydrodynamic vorticity and helicity fields and I will show how such flows inform the anisotropic accretion onto galaxies, leaving clear signatures in the kinematics of galaxies and in the scatter of scaling relations such the j*-M* relation, with specific features for central and satellite galaxies. Starting from our recent detection of spin alignments with cosmic filaments in SAMI, I will develop how the kinematics provided by IFS surveys can be used as a powerful tool to not only detect the connection between galactic angular momentum and cosmic filaments but also to infer information from the very cosmic flows that gave rise to the observed population of galaxies.

Patrick Drew (University of Texas at Austin)

Caitlin Casey (University of Texas at Austin)
Susan Kassin (Space Telescope Science Institute)
Raymond Simons (Johns Hopkins University)
Chao-Ling Hung (Manhattan College)

Topic: Galaxy Evolution Mechanisms

Flat Rotation Curve of Disk Galaxy, DSFG850.95 at z ~ 1.6

The evolution of the dark matter to baryon fraction in galaxies through cosmic time is a fundamental test for cosmological formation models. At low redshift, outer regions of disk galaxies exhibit flattened rotation curves due to high dark matter fractions. Simulations show dark matter halo concentration should decrease with increasing redshift, implying baryons may dominate over dark matter instead in the outer regions of galaxies at sufficiently high redshift. Recent studies have found galaxies at z ~ 2 host declining rotation curves, which they attribute to decreased dark matter fractions and the increased ionized gas pressure support present at high redshift. We present Halpha and [NII] observations obtained w ith the MOSFIRE spectrograph on Keck of a disk galaxy at z = 1.555 that is a counter example to these works, hosting a flattened rotation curve out to exceptionally high galactocentric radii of ~17 kpc. The galaxy, DSFG850.95, is typical of high redshift disk galaxies in many ways. It lies on the stellar mass Tully Fisher relation and the main sequence of star forming galaxies, has a maximum rotational velocity of 250 km/s, an ionized gas velocity dispersion of 50 km /s, and a star formation rate of 300 solar masses/yr. These findings suggest dark matter halo contractions may not strongly evolve in the last 7 Gyrs. More observations of high redshift disk rotation curves are needed to infer the global evolution of dark matter fractions with cosmological time.

Laura Lenkic (University of Maryland, College Park)

Alberto D. Bolatto (University of Maryland, College Park)

Topic: Galaxy Evolution Mechanisms

Results from a CO Line Search in the Plateau de Bure High-z Blue Sequence Survey Data

We report on the results of a blind line search in 115 CO(2-1) and CO(3-2) observations from the second Plateau de Bure High-z Blue-Sequence Survey (PHIBSS2). These observations are part of a 4-year legacy program at the IRAM Plateau de Bure Interferometer aimed at studying early galaxy evolution from the perspective of molecular gas reservoirs. The targeted (primary) galaxies were selected from the 3D-HST/CANDELS fields to lie on the main sequence of star formation. We find a number of tentative secondary detections in the data, with 46 out of the 115 data cubes showing possible secondary sources in addition to the targeted primary source. We perform a search for optical counterparts to the additional serendipitous CO detections. The additional CO line candidates do not have the same selection biases as the sample of targeted objects, since they were not pre-selected for observation based on their optically-derived star formations rates and stellar masses. We use the catalog of CO detections to derive luminosity functions for CO(2-1) and CO(3-2) in redshift bins ranging from $z \sim 0.4 – 3$ and compare these to previous observational and theoretical constraints on the CO luminosity functions, and possible clustering of gas-rich galaxies.

Fabian Walter (Max Planck Institute for Astronomy)

Topic: Galaxy Evolution Mechanisms

Evolution of Gas Content Through Cosmic History

The temporal evolution of the cosmic star formation rate density is now well established out to high redshift. This star formation rate density shows a clear peak at z~1-2 that is about one order of magnitude higher than today. The cause for this behavior must be driven by the properties of the underlying reservoir of molecular gas, the fuel for star formation galaxies. The last decade has seen dramatic progress in quantifying the molecular gas content in galaxies through cosmic times, through various observational camapigns. In this talk, I will summarize our current view of the molecular gas content in distant galaxies. This will include some of the recent results emerging from ASPECS: The ALMA SPECtroscopic Survey in the Hubble Ultra-Deep Field (UDF). This ALMA large program provides a census of molecular gas in high-redshift galaxies through full frequency scans at approximately uniform line sensitivity. The resulting cosmic molecular gas density as a function of redshift shows a factor 3-10 decrease from z=2 to z=0. The cosmic star formation history therefore appears to be at least partly driven by the increased availability of molecular gas reservoirs at the peak of cosmic star formation (z~2).

Kristina Nyland (NRAO)

Topic: Galaxy Evolution Mechanisms

Uncovering the Impact of Jet-ISM Feedback on Galaxy Evolution in the ngVLA Era

Energetic feedback by Active Galactic Nuclei (AGNs) plays an important evolutionary role in the regulation of star formation on galactic scales. However, the effects of this feedback as a function of redshift and various galaxy properties such as mass, environment and cold gas content remain poorly understood due to the demanding sensitivity requirements for current radio telescopes. The ground-breaking improvements in sensitivity, resolution, and frequency range of the ngVLA will facilitate large studies linking information on radio morphology, energetics, and source ages based on deep, high-resolution continuum observations with atomic and molecular gas data tracing the ISM content and conditions. This will provide an unprecedented opportunity to survey the effects of jet-ISM feedback in different environments and cosmic epochs. To emphasize the unique parameter space probed by the ngVLA, I will present an analysis of recent imaging simulations demonstrating that the current reference design is well-suited for studies compact, young radio jets with extents ranging from a few pc to a few kpc that are likely to be interacting with the star-forming cold gas reservoirs of their hosts. In concert with multiwavelength ancillary data from instruments including ALMA, the SKA, and *JWST*, the ngVLA will play a key role in dramatically advancing our understanding of the physics of radio AGN feedback and its complex connection with galaxy evolution.

Avani Gowardhan (Cornell University)

Dominik Riechers (Cornell University)
Henrik Spoon (Cornell University)
Eduardo González Alfonso
Duncan Farrah
Jacqueline Fischer
Jeremy Darling (University of Colorado)
Chiara Fergulio
Jose Afonso
Luca Bizzocchi

Topic: Galaxy Evolution Mechanisms

Extreme feedback in AGN-Starburst Systems: Detailed Insight from Multi-Faceted Molecular Gas Studies

Feedback from active galactic nuclei and/or nuclear starbursts - in the form of outflowing molecular gas - is frequently invoked in galaxy evolution models to explain the decline of the galaxy luminosity function and the emergence of the black-hole - bulge property correlations, but the physics of such outflows are still poorly constrained. We present dense and diffuse molecular gas observations using VLA/ALMA/NOEMA for the most extreme molecular outflows known in the local universe (outflow velocities > 1500 km/s), revealing luminous, time-variable megamaser emission from the outflowing cold molecular gas and demonstrating the necessity of multiple molecular gas tracers to study the diverse physical conditions prevalent in outflows. We also discuss how ngVLA will revolutionize our understanding of feedback physics with spatially resolved sub-kpc mapping of OH megamaser emission outflow dynamics out to intermediate redshifts (z >~ 0.5).

Yuki Yamaguchi (Institute of Astronomy, the University of Tokyo)

Kotaro Kohno (Institute of Astronomy, the University of Tokyo; Research Center for the Early Universe, The University of Tokyo)
Bunyo Hatsukade (Institute of Astronomy, the University of Tokyo)
Tao Wang (Institute of Astronomy, the University of Tokyo; National Astronomical Observatory of Japan)
and ASAGAO team

Topic: Galaxy Evolution Mechanisms

ALMA Twenty-six Arcmin^2 Survey of GOODS-S at One-millimeter (ASAGAO): Physical Properties of ALMA-selected Galaxies

We present the results of a multi-wavelength analysis of λ = 1.2 mm continuum sources detected by the deep and wide-field (~ 26 arcmin^2) ALMA survey, ASAGAO (PI: K. Kohno, Project ID: 2015.1.00098.S). Based on the ASAGAO final map which was created by combining ASAGAO and ALMA archival data in the GOODS-South field (Project ID: 2015.1.00543.S and 2012.1.00173.S), we extract 598 continuum source candidates with signal-to-noise ratio (S/N) > 3.5 ($1\sigma \sim$ 30-70 μJy beam^{-1}). By exploiting the high angular resolution of ASAGAO (0''.59 × 0''.53), we find that 66 ASAGAO sources have *K*-band counterparts in ZFOURGE catalog (Straatman et al. 2016).

The median redshift of these ASAGAO sources is estimated to be $z_{\rm median} = 1.70 \pm 0.21$, which is consistent with results of faint (sub-)millimeter sources ($S_{\rm obs}$ < 1 mJy) detected in recent ALMA deep surveys (e.g., Dunlop et al. 2017). This median redshift is lower than that of blight (sub-)millimeter galaxies ($z_{\rm median} \sim$ 2.1-3.1; e.g., da Cunha et al. 2015) and this result seems to be the direct consequence of the redshift evolution of the IR luminosity function. We estimate their stellar masses and star formation rates (SFRs) by optical-to-millimeter SED fittings. We find that they generally follow the tight relationship on the stellar mass versus SFR plane in the range of $M_* \sim 10^{9\text{-}12}$ $M_{\rm sun}$ and SFR ~ $10^{0\text{-}3}$ $M_{\rm sun}$ yr^{-1} (i.e., a main sequence of star-forming galaxies) although some sources show starburst-like features. ALMA selected sources exhibit systematically larger infrared excess (IRX = $L_{\rm IR}/L_{\rm UV}$) compared to ZFOURGE galaxies without ALMA detections. This suggests that properties of dust-obscured star-formation of ALMA detected sources are different from ALMA non-detected sources even though they have similar star-forming properties. We find that ASAGAO sources with *K*-band counterparts are main contributors to the cosmic infrared SFR density at $z > 2$. On the other hand, fainter population than ASAGAO sources seems to be the main contributor to the infrared SFR density at $z < 2$.

We also extract 5 ASAGAO significant sources (S/N > 5) without *K*-band counterparts. Their SEDs suggest that they can lie at $z >$ 4-5. Their estimated stellar masses are relatively small (~< $10^{9.0\text{-}10.5}$ $M_{\rm sun}$) although their SFRs ~ 10^2 $M_{\rm sun}$ yr^{-1}. This implies that they can represent the early phase of formation of massive galaxies as suggested by Wang et al. (2016). We estimate their contribution to the cosmic SFR density (~ 1.3×10^{-2} $M_{\rm sun}$ yr^{-1} Mpc^{-3}), which can be consistent with that of ultraviolet selected galaxies at $z \sim$ 4-5. This result shows that ALMA continuum surveys can unveil the dust-obscured star formation activities, which are missed in previous deep optical/near-infrared surveys. However, follow-up observations of these optical/near-infrared dark sources are time confusing even with ALMA despite their importance to understand the cosmic star formation history. Therefore, they can be good targets of next-generation facilities such as Next Generation Very Large Array or extended-ALMA.

Eric Murphy (NRAO)

Sean Linden (University of Virginia)
Dillon Dong (Caltech)
Brandon Hensley (JPL)
Emmanuel Momjian (NRAO)
George Helou (IPAC/Caltech)

Topic: Galaxy Evolution Mechanisms

A New Detection of Extragalactic Anomalous Microwave Emission in a Compact, Optically-Faint Region of NGC 4725

We present a new likely detection of extragalactic Anomalous Microwave Emission (AME) in a discrete, compact region (NGC 4725 B) ~1.9kpc from the nucleus of NGC 4725. Based on detections at 3, 15, 22, 33, and 44 GHz, NGC 4725 B is a uJy radio source peaking at 33 GHz. While the source is not identified in BVRI photometry, we detect counterparts in the mid-infrared IRAC bands (3.6, 4.5, 5.8, 8.0 um) that appear to be associated with dust emission in the central region of NGC 4725. Consequently, we conclude that NGC 4725 B is a new detection of AME, and very similar to a recent detection of AME in an outer-disk star-forming region in NGC 6946. We find that models of electric dipole emission from rapidly rotating ultra-small grains are able to reproduce the radio spectrum for reasonable interstellar medium conditions. Given the lack of an optical counterpart and the shape of the radio spectrum, NGC 4725 B appears consistent with a nascent star-forming region in which young (<3 Myr) massive stars are still highly enshrouded by their natal cocoons of gas and dust with insufficient supernovae occurring to produce a measurable amount of synchrotron emission. Next-generation facilities are critically needed to improve our highly incomplete understanding of the physical mechanism and conditions powering AME.