Poster Abstracts for

Galaxy Evolution Mechanisms

Parallel Session

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Topic: Galaxy Evolution Mechanisms

Galactic Conformity as a Test of Assembly Bias

Galactic conformity is an observed difference in the quiescent satellite galaxy fraction for quiescent versus star-forming central galaxies. Weinmann et al. (2006) first identified *one-halo* conformity in SDSS, while Kauffmann et al. (2013) first claimed to have detected conformity beyond the scale of a single dark matter halo (*two-halo* conformity) in SDSS. Two-halo conformity has since emerged as a test of assembly bias: the dependence of halo clustering on properties beyond halo mass, such as formation epoch and large-scale environment. Hearin et al. (2016) hypothesizes that two-halo galactic conformity is an indirect result of *halo accretion conformity*: a correlation between halo age, environmental density, and dark matter accretion rate. Several studies (Hartley et al. 2015; Kawinwanichakij et al. 2016) have looked for conformity beyond the local universe, but their results are limited to one-halo conformity and hindered by small samples sizes, single-field surveys, and photometric redshifts. Other studies (Paranjape et al. 2015, Tinker et al. 2017; Sin et al. 2017; Sun et al. 2018) have re-examined Kauffmann's original detection of two-halo conformity in SDSS, and found several ways to detect a false conformity signal if hidden variables are not accounted for, including contamination of the central galaxy sample by satellite galaxies, and variation in the stellar-to-halo mass relation for star-forming and quiescent galaxies. The small magnitude of the effect also makes robust detections of two-halo conformity at $z > 0.2$ difficult due to the large survey volumes and redshift precision required. We have conducted the largest-area intermediate redshift ($0.2 < z < 1.0$) one- and two-halo conformity study to date using spectroscopic redshifts of 60,000 galaxies from the PRIsm MUlti-object Survey (PRIMUS). Our sample covers over 5.5 deg^2 in four fields, allowing us to account for cosmic variance. We also control for correlations between quiescent fraction and redshift and stellar mass. While we detect a significant ($> 3\sigma$) one-halo conformity signal of ~5%, the two-halo signal we find is only a 2.5σ detection of ~1%. Ours is the only measurement of conformity at $z > 0.2$ performed with spectroscopic redshifts, and illustrates the need for a next generation of deep, wide-field spectroscopic redshift surveys at $z > 0.2$ to advance our understanding of how galaxy evolution depends on large-scale structure.

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Topic: Galaxy Evolution Mechanisms

No Dust Continuum Overdensities around 6<z<7 Quasars

Bright high-redshift quasars (z>6), hosting supermassive black holes with Mh > 10^9 M_sun, are expected to reside in massive host galaxies embedded within some of the earliest and most massive galaxy overdensities. We analyze 1.2 mm ALMA dust continuum maps of 35 bright quasars at 6<z<7 and search the primary beam for excess continuum emission as evidence for early protoclusters. We compare the >5? (?_avg = 58.6+19.0 uJy) detection rates of continuum sources in the fields surrounding the quasars (a total effective area of 4.3 arcmin^2) with millimeter number counts in blank field surveys. We discover 15 millimeter sources in the fields excluding the quasars themselves, corresponding to an overdensity ?_gal=(N_gal-N_exp)/N_exp=-0.06±0.03, consistent with no detected overdensity of dusty galaxies within 110 kpc from the quasar. However, the apparent lack of continuum overdensity does not negate the hypothesis that quasars live in overdense environments, as evidenced by strong [CII] overdensities found on the same scales to similarly-selected quasars. While protoclusters at z>5 are expected to span over 10 arcmin on the sky, the field of view of ALMA is 20 times smaller and probes physical scales of only 100 kpc, so this search for source multiplicity near the quasar may not be sufficient to detect large-scale overdensities. Quasar feedback could play a role in clearing out its immediate vicinity, cutting off ongoing star formation. A detection of an overdensity in dust continuum would have to be at least ?_gal > 0.9, although the relative mass overdensity that this limit maps to is observationally unconstrained, given uncertainty in the galaxy bias for dust continuum detections. Additional observations over larger angular scales, or a search for spectroscopic counterparts, are necessary to provide a more complete picture of dust continuum emitters in the vicinity of the highest-redshift quasars.

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Topic: Galaxy Evolution Mechanisms

The First Spectroscopic Evidence of Helicoidal Motions Along the Jet of PKS 0521-365 on kpc Scales

The jet activity of active galactic nuclei (AGNs), and its interaction with the interstellar medium, may play a pivotal role in the processes that regulate the growth and star formation of its host galaxy. Observational evidence that pinpoints the conditions of such interaction is paramount to unveil the physical processes involved. We report on the discovery of extended emission-line regions exhibiting an S-shaped morphology along the optical jet of the radio-loud AGN PKS 0521-365 ($z = 0.055$), by using long-slit spectroscopic observations obtained with FOcal Reducer/ low dispersion Spectrograph 2 on the Very Large Telescope. The velocity pattern derived from the [O II] λ3727 Å, H β λ4861 Å and [O III] $\lambda\lambda$4959, 5007 Å emission lines is well fitted by a sinusoidal function of the form: $v(r) = \alpha r^{1/2} \sin(\beta r^{1/2} + \gamma)$, suggesting helicoidal motions along the jet up to distances of 20 kpc. We estimate a lower limit for the mass of the outflowing ionized gas along the jet of $\sim 10^4$ $M_\odot$. Helical magnetic fields and jet precession have been proposed to explain helicoidal paths along the jet at pc scales; nevertheless, it is not clear yet whether these hypotheses may hold at kpc scales.

Daniel P. Cohen (UCLA)

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Topic: Galaxy Evolution Mechanics

The Structure of Feedback Near an Embedded Super Star Cluster

Massive star clusters, particularly super star clusters (SSCs), are fundamental components of galactic evolution. Although still embedded in their natal gas clouds, the youngest SSCs excite luminous HII regions, or "supernebulae", which are detected as compact radio sources. We present ~0.1″=1.8 pc resolution observations of the K-band continuum and Br α 4.5 μm emis-sion line towards the supernebula in NGC 5253, acquired with NIRSPEC on Keck II with adap-tive optics, NIRSPAO. We register the K-band image with visible HST imaging and VLA/ALMA maps, and find that the K-band/Br α peak is coincident with a warm CO cloud but is completely obscured in optical light. The supernebula exhibits a narrow Br α line (FWHM~65-76 km s^{-1}), despite the presence of ~2000 O stars within a r~3 pc core. The inferred linewidths are similar to measurements of individual compact HII regions in our Galaxy. The Br α velocity structure reveals no high-velocity outflow. We suggest that the supernebula comprises many separate compact wind regions around individual massive stars that are stalled in expansion due to criti-cal radiative cooling, unable to drive a cluster wind. Feedback is apparently ineffective at dis-persing gas from the SSC, and the cluster may continue to form stars out of its enriched gas. With the sensitivity and resolution achievable using current and planned facilities (e.g. ALMA, VLA, ngVLA), it will be possible to characterize a larger sample of SSCs and understand their role in galaxy evolution.

Alison Crocker (Reed College)

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Topic: Galaxy Evolution Mechanisms

Cold Gas Content Versus Spiral Morphology

This study differentiates between grand-design and flocculent spiral galaxies. While spiral arms are locally the sites of enhanced star formation within galaxies, it is less clear that a strong two-arm (grand-design) spiral pattern globally enhances star formation. Here, we report on the specific cold gas content of grand-design versus flocculent spiral galaxies. Galaxy Zoo 2 data are used for morphological classification (Hart et al. 2016), GASS for the HI data (Catinella et al. 2010) and COLD GASS for the CO data (Saintonge et al. 2011). We confirm Hart et al. 2017's result that grand-design spirals, as a population, are more deficient in HI than flocculent galaxies. But we see an even stronger result in the specific H_2 content, finding that grand-design spirals are even more significantly deficient in cold molecular gas. Therefore, it is not the case that the strong two-arm pattern has simply concentrated the cold gas into high H_2/HI ratio spiral arms, but that the global cold gas content of grand-design spirals is lower than that of flocculent spirals. Given similar specific star formation rates found for these two populations, local grand design spirals are more efficient at converting what gas they have into stars than local flocculent galaxies, which can be seen in the distribution of gas depletion times for both types of spirals.

Daniel Dale (University of Wyoming)

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Topic: Galaxy Evolution Mechanisms

An ALMA-HST Study of Cold Dust Emission and Star Clusters

We present results from a joint ALMA-HST study of the nearby galaxy NGC628. A comprehensive database for 1000+ star clusters is combined with new ALMA observations of the cold dust continuum in NGC628. We find evidence for excess dust emission at millimeter/sub-millimeter wavelengths. The excellent resolution of the ALMA maps--approximately 20 pc at the distance of NGC628--allows us to constrain the spatial variations in the slope of the cold dust emission with the ages and masses of the nearby star clusters.

Courtney Dressing (University of California, Berkeley)

LUVOIR Mission Concept Team

Topic: Galaxy Evolution Mechanisms

Probing Stars, Galaxies, & Cosmology with the Large UV/Optical/IR Surveyor

LUVOIR is a concept for a powerful and flexible observatory designed to revolutionize our view of the universe. Operating at the Sun-Earth Lagrange 2 point, LUVOIR will gaze at the skies at far-UV to near-IR wavelengths, with a large aperture of 8-15 m and sophisticated instrument suite: an ultra-high contrast coronagraph (ECLIPS); a high-resolution imager (HDI); a multi-resolution, multi-object UV spectrograph and imager (LUMOS); and a UV spectropolarimeter (POLLUX). LUVOIR will acquire exquisitely deep images of the universe at unprecedented resolution, advancing multiple facets of astronomy and complementing ground-based observations from future facilities. In addition to detecting and characterizing exoplanets orbiting nearby stars and improving our view of the Solar System, LUVOIR will conduct groundbreaking studies of stars, galaxies, and cosmology. For instance, LUVOIR will advance stellar astronomy by resolving stellar populations, studying stellar winds, and investigating the stellar initial mass function. By resolving star-forming regions of galaxies 10-25 Mpc away, LUVOIR will probe the abundances and kinematics of stars in a much more diverse set of galaxies and pursue pioneering investigations of galaxy evolution. Extremely deep UV observations with LUVOIR will yield new views of the intergalactic medium and significantly advance our understanding of the cycling of matter within, among, and near galaxies. Furthermore, LUVOIR's ability to image extremely faint and small structures will facilitate detailed studies of ultra-faint galaxies and the nature of dark matter. As a community-driven facility, LUVOIR will be used by astronomers around the world to pursue a wide range of investigations and address the science questions of the 2030s and beyond.

Meredith Durbin (University of Washington)

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WINGS Science Investigation Team

Topic: Galaxy Evolution Mechanisms

Recovering Ages & Metallicities of Stellar Halos with WFIRST

Ground-based surveys such as SDSS and PandAS have revealed rich substructure in Local Group galactic halos. WFIRST's unprecedented combination of depth, field of view, and resolution has the potential to extend such studies out to the entire Local Volume. Here we present an initial assessment of WFIRST's ability to measure ages and metallicities of resolved stellar populations such as one might find in galactic halos. We simulate two-band WFI photometry of single-age, single-metallicity stellar populations at fixed stellar mass (10^7 $M_\odot$) and a range of distances, ages, and metallicities, and perform star formation history fits using MATCH (Dolphin 2002). We find that WFIRST is capable of fitting star-formation histories with 80% accuracy for all input ages and metallicities out to 6 Mpc, and with 50% accuracy out to 8 Mpc.

Brian Eisner (Macalester College)

Topic: Galaxy Evolution Mechanisms

Surveying Radio Line Spectra of Nearby Galaxies

Astrochemistry revolves around the observations of molecular transitions, which trace a variety of physical parameters such as shocks, temperatures, and densities. Centimeter wavelengths hold promise for the field, but remain understudied. Spectra of astronomical objects at millimeter and submillimeter wavelengths are approaching the limit of line saturation, decreasing the yield of any future instruments at these higher frequencies. In addition, transitions of complex molecules are often located in the centimeter wavelengths, and represent better reservoirs of information than simpler molecules due to increased degrees of freedom. The upcoming Next-Generation Very Large Array (ngVLA) will represent a 10x increase from the sensitivity of current instruments, potentially allowing extragalactic observations of these complex molecules. We sample the 4cm- or 15mm-band of nine nearby star-forming galaxies using the Australia Telescope Compact Array in its H75 (4cm beam ≈140″, 15mm beam ≈40″) configuration. Our velocity resolution ranges from ≈13 km s^{-1} at the low-frequency end to ≈2.5 km s^{-1} at the high-frequency end (resulting 4cm RMS ≈ 1 mJy bm^{-1} and 15mm (RMS ≈ 4 mJy bm^{-1}). The galaxies in our sample display transitions from radio recombination lines (RRLs) and five different molecular species to thresholds of ≈1 mJy: H_2CO, H_2O, OH, NH_3, and c-C_3H_2. RRLs dominate the 4cm-band, while the 15mm-band has a higher density of molecular lines. Notably, $^2\Pi_{3/2}$ OH is detected in the highly-excited J=9/2 state in NGC 4945 and Circinus, only the third and fourth extragalactic detections of this state, while a potential NH_3 (3,3) maser is detected in NGC 4945. The ngVLA will be able to prove a ≈150 times larger number of galaxies to study to the same S/N ratio as our sample. A larger variety of galaxies will similarly be available for study, and complex molecules should be observable in the closest galaxies.

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Topic: Galaxy Evolution Mechanisms

Downsizing of Star Formation Measured from the Clustered Infrared Background Correlated with Quasars

Powerful quasars can be seen out to large distances. As they reside in massive dark matter haloes, they provide a useful tracer of large-scale structure. We stack *Herschel*-SPIRE images at 250, 350, and 500 microns at the location of 11,235 quasars in ten redshift bins spanning $0.5 \leq z \leq 3.5$. The unresolved dust emission of the quasar and its host galaxy dominate on instrumental beam scales, while extended emission is spatially resolved on physical scales of order a megaparsec. This emission is due to dusty star-forming galaxies clustered around the dark matter haloes hosting quasars. We measure radial surface brightness profiles of the stacked images to compute the angular correlation function of dusty star-forming galaxies correlated with quasars. We then model the profiles to determine large scale clustering properties of quasars and dusty star-forming galaxies as a function of redshift. We adopt a halo model and parameterize it by the most effective halo mass at hosting star-forming galaxies, finding $\log(M_{eff}/M_{\odot})=13.8^{+0.1}_{-0.1}$ at $z=2.21$-2.32, and $\log(M_{eff}/M_{\odot})=10.7^{+1.0}_{-0.2}$ at $z=0.5$-0.81. Our results indicate a downsizing of dark matter haloes hosting dusty star-forming galaxies between $0.5 \leq z \leq 2.9$. The derived dark matter halo masses are consistent with other measurements of star-forming and sub-millimeter galaxies. The physical properties of dusty star-forming galaxies inferred from the halo model depend on details of the quasar halo occupation distribution in ways that we explore at $z>2.5$, where the quasar HOD parameters are not well constrained.

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Topic: Galaxy Evolution Mechanisms

Spatially Resolved ALMA Observations of Lensed Submillimeter Galaxies, SDP.81 and SDP.9.

Submillimeter Galaxies (SMGs) have been known as prolific star-formers in the early epoch of the universe. It, however, has not been well understood how such an intense star formation occurs partly due to lack of spatial resolution. Here, we report observational results of two lensed SMGs, SDP.81 (z=3.042) and SDP.9 (z=1.5747). Strong gravitational lensing extends observed images and allows us to probe much more detailed structures of galaxies.

For SDP.81, we observed a [CII] 158 um line as a ALMA cycle 4 program in 2016. The observation was conducted at Band 8 (469 GHz) and the synthesized beam size is 286x259 mas. Due to the magnification, the effective resolution reaches ~400 pc at z=3.042. The velocity-integrated flux is 158 +/- 31 Jy km/s, which is significantly weaker than a previous observation by *Herschel* (840 +/- 120 Jy km/s) (Valtchanov et al. 2011). This possibly could attribute to the missing flux by resolving out extended structures. Using a mass model of the foreground galaxy presented by Tamura et al. 2015, we reconstruct the 3D data cube on the source plane. The source plane can be well explained by two components; one is an ordered rotation feature, which has been already known by previous CO observations by ALMA (ALMA Partnership et al. 2015), and the other is an expanding feature, which has not been seen before. We consider that this peculiar velocity structure is a proof of an expanding shell-like atomic outflow. Based on an expression in Maiolino et al. 2012, we put a lower limit on the outflow mass rate of 190 M_{Sun}/yr. This value is comparable to SFR of 527 M_{Sun}/yr (Negrello et al. 2014) and it is consistent with the fact that molecular outflow mass rate is comparable to SFR in starbursts (Cicone et al. 2014). We also discuss the energy source of the outflow and find that either radiation pressure by O/B type stars or supernovae could sufficiently drive the outflow.

For SDP.9, we observed a CO(6-5) line as a ALMA cycle 3 program in 2015 (Wong et al. 2017). We reconstruct the 3D data cube on the source plane and find that this system shows a purely ordered rotation feature. Combined the data of *HST* WFC/F160W, there is a clear offset between stellar components and dust/gas components. We have to be careful that there is an astrometric error between *HST* and ALMA, but such an offset has been found in SDP.81 as well. This could be understood as dust obscuration at the nuclear region or tidal features by merging. We also model the velocity field using *3D-Barolo* (Teodoro & Fraternali 2015). From the model, the maximum velocity and dispersion are ~200 km/s and ~60 km/s, respectively. The high ratio (~3) between them suggests that SDP.9 is rotationally supported. This value is consistent with dusty star-forming galaxies at z~2 (Tadaki et al. 2017).

Such powerful synergy between ALMA and strong lensing allows us to probe internal spatial/velocity distribution in galaxies, but the number of resolved samples are quite rare, which leads to the difficulty of statistical interpretation for dusty starbursts. Thus, it is important to conduct follow-up observations using ALMA toward potential candidates (H-ATLAS, SPT, HSC-SSP sources, etc). We believe that this study can be one of the first steps to proceed such observations in the future.

Takuma Izumi (National Astronomical Observatory of Japan)

Keiichi Wada (Kagoshima University)
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Topic: Galaxy Evolution Mechanisms

ALMA Reveals the Molecular and Atomic Obscuring Structures in the Circinus Galaxy

We report ~6 pc resolution CO(3-2) and ~15 pc resolution [CI](1-0) emission line measurements with ALMA (Cycle 4) toward the circumnuclear <100 pc region of the nearest type-2 active galactic nucleus (AGN), the Circinus galaxy (D = 4.2 Mpc). We aimed at revealing multi-phase structure of an AGN torus, which has not been studied in detail so far. Our high resolution observations revealed a wealth of detail. We found that the cold dust distribution traced by our Band 7 (350 GHz) continuum emission delineates the outer boundary of the warm dust distribution probed by near- or mid-IR emission, which indicates that the “torus” has a temperature-dependent structure. The dense molecular gas traced by CO(3-2) emission concentrates toward the central ~50 pc region (circumnuclear disk = CND), providing a sufficient column density that makes this Circinus AGN a Compton-thick one. We found that the detailed distributions of the CO(3-2) and the [CI](1-0) emissions are different: [CI](1-0) is more centrally-peaked. This clearly indicates the XDR-chemistry induced by this AGN, i.e., molecular CO is X-ray dissociated into atomic C. Indeed, we confirmed an increasing trend of [CI](1-0)/CO(3-2) intensity ratio toward the AGN position. Regarding gas dynamics, we found that the dense molecular gas traced by CO(3-2) is confined in a geometrically thin disk, whereas the diffuse atomic gas probed by [CI](1-0) is in a geometrically thicker volume, at the CND-scale. This indicates the existence of the multi-phase structures in the nuclear obscuring material around an AGN. All of the above properties are well-reproduced by our hydrodynamic model that is called a “radiation-driven fountain” torus model, where the circumnuclear obscurer consists of (i) ionized gas outflows and failed wind that falls back to the disk, (ii) geometrically thin dense molecular gas disk, and (iii) geometrically thick atomic (and partially molecular) gas that is puffed-up by the turbulence induced by the failed winds. These findings would require a significant refinement of the widely-accepted simple donut-like “torus” picture.

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Topic: Galaxy Evolution Mechanisms

Resolved ALMA Observations of Water Emission from High Redshift Galaxies

H_2O is one of the most abundant molecules in the warm interstellar medium and some transitions can be as bright as mid-J CO lines. Observations of H_2O in nearby luminous infrared galaxies showed that H_2O traces the local infrared field with L_{H2O}/L_{IR} ratio remaining constant over about five orders of magnitude in L_{IR}. H_2O (2_{02}-1_{11}) 987.927 GHz, which is one of the brightest water emission lines, couples efficiently to the far infrared field, but is largely insensitive to the radiation shorter than 50 um rest frame. This implies that it traces the infrared emission from star forming regions (hence, star formation rate) and is largely insensitive to the presence of an active active galactic nucleus. In this talk, we present the first ever resolved kpc ALMA observations of H_2O (2_{02} - 1_{11}) in three high redshift ($z \sim 3$) gravitationally lensed dusty star forming galaxies (DSFGs) selected from the South Pole Telescope survey. We find that L_{H2O} is correlated with L_{IR} at resolved kpc scales within the galaxy as it does at the global scale. With more such resolved observations in the future, we intend to develop H_2O (2_{02} - 1_{11}) as a resolved star formation rate indicator.

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Topic: Galaxy Evolution Mechanisms

z ~ 3 Ionizers in the GOODS-N Field

We use deep F275W imaging from the *Hubble* Deep UV Legacy Survey, G280 grism spectroscopy from *HST*/WFC3, and new and archival optical spectra from Keck/DEIMOS to search for candidate sources of Lyman continuum radiation at $z \sim 3$ in the GOODS-N field. Spectroscopic identifications of our UV-selected sources are 94% complete to F275W = 25.5 in the region of the UV imaging. We identify 6 potential ionizing galaxies or active galactic nuclei (AGNs) at $z \sim 3$, the brightest of which is a $z = 2.583$ quasar that dominates the ionizing flux in this volume with a specific ionizing volume emissivity at 912 Å of $ee_{912} = 8.3$ ´´ 10^{24} erg s^{-1} Hz^{-1} Mpc^{-3}, consistent with providing all the flux necessary to maintain an ionized intergalactic medium at $z \sim 3$. Based on spectroscopic evidence, four candidates are found to be contaminated by foreground galaxies at low redshift. The remaining candidate galaxy's contribution to the ionizing background is a factor of ~38 smaller than that of the EUV-bright quasar and lies well below the flux required to ionize the intergalactic medium at $z \sim 2.5 - 3$. We discuss our results in the context of epoch-of-reionization research and explore near-future prospects for the field.

Sandeep Kumar Kataria (Joint Astronomy Program, Indian Institute of Astrophysics, Bangalore)

Mousumi Das (Indian Institute of Astrophysics, Bangalore)

Topic: Galaxy Evolution Mechanisms

The Impact of Bulges on Bar Formation and Bar Pattern Speed in Disk Galaxies

We use N-body simulations of bar formation in an isolated galaxy to study the effect of bulge mass and bulge concentration on bar formation and bar pattern speed. Two sets of models are generated, one that has a dense bulge and high surface density disk and a second model that has a less concentrated bulge and a lighter disk. Our simulations of both the models show that there is an upper cut-off in bulge to disk mass ratio Mb/Md above which bars cannot form; the cut-off is smaller for denser bulges(Mb/Md = 0.2) compared to less denser ones (Mb/Md = 0.5). We define a new criterion for bar formation in terms of bulge to disk radial force ratio (Fb/Fd) at the disk scale length above which bars cannot form and show that if Fb/Fd > 0.35, a disk is stable against bar formation. This criteria agrees with the observations of S0 galaxies which are often bulge dominated and have a very low fraction of bars. We have also studied the effect of bulge mass on bar pattern speed. We find that all bars initially rotate fast with R<1.4, where R is the ratio of corotation radii to bar semi-major axis. This agree with recent observations that show that most bars are fast (e.g. Califa Survey) irrespective of Hubble type. Further our study shows that bar pattern speed decreases with time and after 10 Gyr of evolution, bars become slower (R>1.4). We also find that the net decrease in pattern speed increases with bulge mass.

Mihir Kulkarni (Columbia University)

Greg Bryan (Columbia University), Eli Visbal (CCA, Flatiron Institute)

Topic: Galaxy Evolution Mechanisms

Fragmentation in Ionized Population III Galaxies

Population III stars are typically expected to form in minihalos of mass 10^5 -10^6 M⊙. Molecular hydrogen plays an important role in cooling of the gas in these minihalos. The collapse can be delayed by soft UV radiation dissociating molecular hydrogen and even further by an ionizing radiation. We use cosmological simulations to study the formation of population III stars in dark matter halos exposed to strong ionizing background radiation. For high ionizing fluxes, gas collapse and star formation can be delayed because of ionization and photoheating up to halo masses significantly higher than the atomic cooling threshold. We carry out a numerical investigation of the fragmentation process and the initial mass function of star forming clumps in massive Population III galaxies. In a particular halo studied in detail, we find one clump of mass 5000 M⊙ and a few $100 - 400$ M⊙ mass clumps in 3 Myrs of evolution after the first runaway collapse. Studying the formation of late-forming Population III galaxies is particularly interesting now given their possible observability with JWST.

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Topic: Galaxy Evolution Mechanisms

A Comparative Study of Star-Forming Regions in Luminous Galaxy Mergers and Normal Star-Forming Galaxies in the Local Universe

Galaxies evolve through a combination of secular processes (e.g. cold gas accretion), and non-secular processes (e.g. galaxy mergers), which can trigger massive starbursts and powerful AGN. Local luminous infrared galaxies (L_{IR} [8 – 1000um] > 10^{11} L⊙) are the ideal laboratories for studying the physics of star formation activity in extreme merger-driven environments at low-redshift (z < 0.1). These galaxies are bright, well resolved, and cover the full range of merger stages, from widely separated disk galaxies to single coalesced nuclei. Our group has investigated the activity in U/LIRGs through a combination of space-based (HST, Spitzer, Chandra, Herschel) and ground-based (Keck, ALMA, JVLA) campaigns. The Great Observatories All-sky LIRG Survey (GOALS: Armus et al. 2009) consists of the 202 brightest LIRGs in the IRAS Revised Bright Galaxy Sample (Sanders et al. 2003).

Here, I present the first results from two large Jansky Very Large Array (JVLA) 33GHz (Ka-Band), 15GHz (Ku-Band) and 3 GHz (S-Band) imaging campaigns of star-forming regions in 50 normal star-forming galaxies, taken from the SINGS/KINGFISH legacy survey as part of the Star Formation in Radio Survey (SFRS: Murphy et al. 2018), and 68 LIRGs taken as part of GOALS (Linden et al. 2018 in prep). Although radio emission is energetically weak with respect to a galaxy's bolometric luminosity, it provides a nearly extinction-free view of thermal free-free emission produced by photo-ionized HII regions from massive stars, as well as non-thermal emission from relativistic cosmic rays associated with recent supernova in galaxies. Thus, radio emission is crucial for localizing the sites of recent star-formation activity, particularly in the dusty, compact, environments of U/LIRGs, and allows us to measure the star formation rate surface densities of individual regions in a systematic way across a combined galaxy sample which spans nearly 4 decades in star-formation rate, stellar mass, and molecular gas (H_2) mass.

With wideband radio continuum observations, which sample the full 3-33 GHz frequency range, we have measured luminosities, spectral indices, star-formation rates (SFRs), ages, and infrared luminosities for nearly 300 individual star-forming regions across the combined galaxy sample. Overall, we find that *extranuclear* regions identified in our LIRG survey have radio spectral indices consistent with *circumnuclear* star-forming regions found in the SFRS. Further, we find that the majority of the star-forming regions identified in both surveys have star-formation rate surface densities (Σ_SFR) < 1 M_sun yr^-1 kpc^-2. Our results also indicate that individual star-forming regions in LIRGs are consistent with an extrapolation from luminosity distribution functions measured for galaxies in the SFRS sample. Finally, when we place all regions on the sub-galactic star-forming main sequence of galaxies (SFMS), we find that star-forming regions in LIRGs are not consistent with their host galaxies' globally averaged specific star-formation rates, and together with the SFRS regions, have a considerably shallower SFR-M_* slope. This implies that the nuclear starburst activity drives LIRGs above the SFMS, defined here by the SFRS galaxy sample, and that beyond the nucleus, star-formation appears to proceed normally.

For future work, we plan to link the radio emission with optically visible star-clusters, dust, and ionized and molecular gas maps at matched physical scales, available via ongoing GOALS and SFRS campaigns, to provide a more complete multi-wavelength picture of the evolution of star-formation within extreme starburst environments (seen ubiquitously at high-redshift), relative to the quiescent mode of star formation we see in normal galaxies today.

Jingzhe Ma (University of California at Irvine)

Asantha Cooray (UCI), Arianna Brown (UCI), Hooshang Nayyeri (UCI), Julie Wardlow (Durham), Rob Ivison (Univ. of Edinburgh), Ismael Perez-Fournon (IAC), Dominik Riechers (Cornell), David Clements (Imperial College), Seb Oliver (Univ. of Sussex), Ivan Oteo (Univ. of Edinburgh), Jian Ge (UF), J. Xavier Prochaska (UCSC), Gabriel Brammer (STScI), Britt Lundgren (UNCA), Yinan Zhao (UF), Marcel Neeleman (MPIA)

Topic: Galaxy Evolution Mechanisms

The Formation and Evolution of High-redshift Dusty Galaxies

High-redshift dusty galaxies are excellent sites to investigate mass assembly and growth, star formation rates (both obscured and unobscured star formation), chemical evolution and physical conditions. I will talk about two populations of high-redshift dusty galaxies, submillimeter galaxies and quasar 2175 Å dust absorbers, which are selected by their dust emission and dust absorption, respectively.

I will talk about a large (200+) Spitzer follow-up program of Herschel "red" ($S_{500} > S_{350} > S_{250}$; 500 μm-risers) dusty star-forming galaxies (DSFGs) at z ≥ ~4. With multi-wavelength ancillary data (HST, Keck, ALMA, VLA etc.), we are able to perform SED modeling to derive their physical properties and compare with the more numerous z ~ 2 DSFG population and local LIRGs and ULIRGs. A photometric catalog of the Spitzer/IRAC data for the "red" sources as well as the Herschel-Spitzer cross-matched sources in the fields will be made publically available. Colloquially referred to as 2175 Å dust absorbers or 2DAs due to the broad absorption feature around rest-frame 2175 Å (ubiquitous in the MW), these systems are discovered in the spectra of background z > ~ 2 quasars. Keck, MMT, and VLT spectroscopy shows that these 2DAs tag ISM gas with metallicity and dust depletion levels comparable to our own Galaxy. They are expected to be more massive than DLA galaxies based on the mass-metallicity relation. Simultaneous detections of CI, CO absorption lines with the 2175 Å dust feature indicate large amount of cold gas in the systems and make them ideal targets to search for the corresponding emission lines with ALMA and VLA.

Dusty galaxies such as the two populations provide a laboratory where the unique tools for studying galaxies in emission and absorption can be combined. Synergy between absorption and emission analyses will achieve a more complete picture of gaseous, stellar, metal, and dust content in galaxy formation and evolution, which will be significantly pushed forward by combining ALMA, VLA and JWST.

Carl Melis (UC San Diego)

Amy Mioduszewski (NRAO), Mark Reid (Harvard/CfA), Trent Dupuy (Gemini Observatory), John Stauffer (IPAC/Caltech), Geoffrey Bower (ASIAA), Rachel Osten (STScI/JHU), Laurent Loinard (UNAM/CRyA), Marina Kounkel (Western Washington University), Jim Braatz (NRAO), Lorant Sjouwerman (NRAO), Jan For (Harvard/CfA)

Topic: Galaxy Evolution Mechanisms

VLBI Astrometry: the Pleiades, Comparison to Gaia, and the Future

We present final results from the VLBA Pleiades large program. Four new parallaxes are measured, bringing the total VLBA Pleiades parallax sample to eight systems. Modeling the orbits of two binaries in this sample to obtain system parallaxes also produces individual component masses for four Pleiads, nearly doubling the number of published directly-measured masses for Pleiades stars. The complete sample of VLBA Pleiades parallaxes yields a cluster distance consistent with preliminary results published in 2014; Gaia DR1 results agree well with all VLBI Pleiades astrometry. In an effort to further assess the quality of Gaia data, we compare every VLBI parallax ever measured with its counterpart (if it exists) in DR2; this is one of only a few possible comparisons between Gaia DR2 and astrometric data of similar accuracy and precision. Finally, ngVLA astrometry community study results are presented. We collect a suite of potential science cases and explore how different array configuration and calibration strategy choices impact the ability to pursue each science case.

Ferah Munshi (University of Oklahoma)

Alyson Brooks (Rutgers University)
Jillian Bellovary (CUNY - Queensborough Community College)
Charlotte Christensen (Grinnell College)
Daniel Weisz (UC Berkeley)
Elaad Applebaum (Rutgers University)

Topic: Galaxy Evolution Mechanisms

The MARVELous Dwarfs Meet the Justice League: How Do Dwarf Galaxies Populate Low Mass Halos?

I will present results from high resolution, fully cosmological simulations of 4 cosmic sheets that contain many (isolated) dwarf galaxies [MARVEL dwarfs] as well as dwarfs drawn from 4 volumes containing a Milky Way analogue [the Justice League]. Together, they create the largest collection of simulated dwarf galaxies to date, with z=0 stellar masses comparable to the LMC or smaller. In total, we have simulated 165 luminous dwarf galaxies, forming a sample of simulated dwarfs which span a wide range of physical (stellar and halo mass), evolutionary properties (merger history) and environments. I will show how these dwarfs can be calibrated against a wealth of observations of nearby galaxies including star formation histories, HI masses and kinematics, as well as stellar and gas-phase metallicities. I will present results answering the following key questions: What is the slope of the stellar mass function at extremely low masses? What is the scatter in the stellar to halo mass relationship as a function of dwarf mass? What drives the scatter? I will also comment briefly on the supermassive black holes within some of these simulated dwarfs, and summarize predictions we can make for future gravitational wave missions, like LISA.

Mladen Novak (Max Planck Institute for Astronomy)

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the VLA-COSMOS team and the COSMOS team

Topic: Galaxy Evolution Mechanisms

SubmicroJy Radio Populations Based on the VLA-COSMOS 3 GHz Large Project

We make use of the ~400h VLA radio observations of the COSMOS field at 3 GHz to infer radio luminosity functions using approximately 6000 star-forming galaxies and 1800 AGN hosts up to redshift of z~5.5. This is currently the largest radio-selected sample available out to such high redshift across an area of 2 square degrees with a sensitivity of rms=2.3 ujy/beam. Redshift evolution of each population can be fitted with a two-parameter pure luminosity evolution model. We estimate star formation rates (SFR) from our radio luminosities using an IR-radio correlation that is redshift dependent. Our data suggest that the cosmic SFR density (SFRD) history peaks about z~2.5 and that the ultraluminous infrared galaxies contribute up to ~25% to the total SFRD at the same redshift. We find evidence of a potential underestimation of the SFRD based on the UV rest-frame observations of Lyman break galaxies. Finally, we use our evolution models to calculate the radio source number counts down to sensitivity limits of the next generation radio surveys. Our work suggests that radio emission in galaxies with 1.4 GHz flux densities between 0.1 and 10 μJy will be dominated by star-formation processes in 90-95% of the cases, with a high percentage of these galaxies existing around a redshift of z~2 (Novak et al. 2018).

Jürgen Ott (National Radio Astronomy Observatory)

David Meier (New Mexico Institute of Mining and Technology)
Nico Krieger (Max-Planck-Institut für Astronomie)
Mark Gorski (University of Western Ontario)
Adam Ginsburg (National Radio Astronomy Observatory)

Topic: Galaxy Evolution Mechanisms

K-band Water Masers and Ammonia Thermometry with the ngVLA

The ngVLA will revolutionize cm observations given its extreme collecting area, wide field of view, and its large range of long and short baselines that cover structures from entire galaxies to individual molecular cores at 1cm wavelength. K-band is a fundamental frequency band for spectroscopy of galaxies, given its rich spectrum including the 22GHz water maser, tens of ammonia inversion transitions, radio recombination lines, as well as bright tracers of shocks and photon-dominated regions. Over the last few years, we have surveyed this frequency range across the Galactic Center and bright, nearby galaxies with the ATCA and the VLA (SWAG and SWAN surveys: "Survey of Water and Ammonia in the Galactic center/Nearby galaxies"). We show that the ngVLA will allow detections of water masers associated with individual young stellar objects (YSOs) in the entire Local Volume and the four order of magnitude weaker lines from the outflows of AGB stars, in the nearby universe. The YSOs will give us an unobscured measure of the star formation activity of a galaxy and the AGB star masers will open up a radio study of the evolved stars that shape the structure, elemental abundance, and mass enrichment of galaxies. In addition, we will be able to probe water megamasers to the low end of the supermassive black hole mass scale. Ammonia precision thermometry, which is currently only possible to distances of ~5Mpc, will reach beyond the Local Volume with the ngVLA, with an increase in observable volume of ~3000. We will thus be able to apply the ammonia thermometer to a much larger variety of galaxies and probe ISM heating/cooling mechanisms as a function of galaxy type and internal environment down to the scales of individual clouds. Furthermore, the ngVLA will reach to the peak of galaxy and star formation at z~1-2 when observing ammonia in absorption. The precision measurements will allow a completely new approach to derive the star formation properties of the galaxies, their molecular gas reservoir, dynamical and radiative heating and cooling mechanisms, and energetic feedback from black holes and stars, which are essential to test galaxy evolution scenarios.

Sameer (Pennsylvania State University)

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A. Myers (University of Wyoming)
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Topic: Galaxy Evolution Mechanism

X-ray observations of transforming BAL quasars

We report on an X-ray and optical/UV study of eight Broad Absorption Line (BAL) to non-BAL transforming quasars at z ~ 1.7-2.2 over 0.29-4.95 rest-frame years with at least three spectroscopic epochs for each quasar from the SDSS, BOSS, Gemini, and ARC 3.5m telescopes. New Chandra observations were obtained for these objects in Cycle 16. Their values of α_{ox} and $\Delta\alpha_{ox}$, as well as the spectral energy distributions, are consistent with those of non-BAL quasars. Moreover, our targets show evidence for X-ray spectral shapes that are consistent with weakened absorption with an effective power-law photon index of $\Gamma_{eff} = 2.36^{+0.57}_{-0.47}$ The newer Gemini and ARC 3.5m spectra show that the BAL troughs have remained gone since their BOSS observations in all but one case. The X-ray and optical/UV results in tandem are consistent with absorbing material moving out of the line-of-sight, leaving an X-ray unabsorbed non-BAL quasar.

Tabassum S Tanvir (University of Hertfordshire)

James E Dale (University of Hertfordshire)

Topic: Galaxy Evolution Mechanisms

A Comprehensive Study of Collisions Between Giant Molecular Clouds

We present the results from a recent batch of simulations done on turbulent cloud collision using the smooth particle hydrodynamics code GANDALF [1]. Since galactic-scale simulations cannot adequately resolve cloud collision [2] it is of interest to explore such events to understand their influence on the star formation process within the clouds. In our simulations we have explored different initial conditions (e.g.: relative velocity, mass ratio, individual cloud virial ratio, impact parameter etc.) of these clouds and analyzed the influence of these initial conditions on the star formation process and the structure and dynamics of the collision-product. The ranges of these parameters are already known from observations or galactic scale simulations. Our study has also investigated the effect of ionization feedback [3] on such events, on the star formation rates and efficiencies, and on the cloud structures in position-position and position-velocity space.

References:

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Wynne M. Turner (University of California, Los Angeles)

Steven R. Furlanetto (University of California, Los Angeles), Jordan Mirocha (University of California, Los Angeles)

Topic: Galaxy Evolution Mechanisms

Modeling Spectra of Primordial Galaxies in Presence of Interstellar Dust

Light from the first galaxies can provide key information about the nature of the universe shortly after the Big Bang. Using model galaxy spectra as inputs, I have written a program in Python to compute the emergent spectra in the presence of interstellar dust. Taking into account various dust extinction laws cited in the literature, interpolated across a wide redshift range, the results from each case are plotted to illustrate their disparity. These findings help increase understanding of how observed spectra have been altered due to interstellar dust, and accordingly, knowledge of the composition of the early universe.

Catherine Witherspoon (University of Wisconsin – Madison)

Eric Wilcots (University of Wisconsin – Madison)
Monica Sanchez (NRAO)

Topic: Galaxy Evolution Mechanisms

Evolution of Intermediate Mass Galaxies in the CHILES Field

We present the results of our analysis of intermediate mass galaxies in the COSMOS HI Large Extragalactic Survey (CHILES) field based on data from the Davies spectroscopic catalog (Davies et al. 2015). Using the *Very Large Array*, CHILES is a 1000 hour single-pointing of a 40’ cone in the COSMOS field observing galaxies at 21cm for redshifts $0 < z < 0.45$. The goal of our research is to determine what stellar mass range of galaxies might have undergone the most evolution from $0 < z < 0.45$. Out of the more than 400,000 galaxies in the COSMOS field, 2,761 fall within the CHILES field. Based on the method described in Catinella et al. (2010) for estimating the HI total mass from the NUV-r color and surface stellar mass density, we expect to detect approximately 600 galaxies. Splitting these galaxies into low ($< 10^9\ M_\odot$), intermediate ($10^9\ M_\odot < M < 10^{10}\ M_\odot$), and high ($> 10^{10}\ M_\odot$) stellar mass bins, we compare the SDSS *u-r* colors, HI total masses, and redshifts. We find that the galaxies that seem to have evolved the most from $0 < z < 0.45$ are the intermediate mass galaxies.