Recipes to Regulate STAR FORMATION at ALL SCALES: From the NEARBY UNIVERSE TO THE FIRST GALAXIES

STScI

2024 SPRING SYMPOSIUM

Star formation is a fundamental process defining galaxies, impacting virtually every facet of astronomy. However, precise mechanisms governing star formation activity,

including but not limited to stellar and AGN feedback, and its evolution with redshift remain a subject of intense debate. With recent observations from cutting-edge (ground-based and space telescopes) observatories (e.g., JWST, HST, ALMA, VLT, Keck) unprecedented data have become available to study star formation at all redshifts. While state-of-the-art simulations are aiding us in the construction of increasingly more realistic models of galaxy formation and evolution to predict and interpret these observables, high redshift observations cannot provide the level of cloud-scale physical detail that the nearby galaxies have to offer. The 2024 STScl Spring Symposium aims to gather the low, intermediate and high-redshift communities to discuss the factors that affect star formation in galaxies, from parsec to kiloparsec and megaparsec scales. We will highlight new observational, theoretical and computational results from the nearby Universe to Cosmic Noon (z~2-3) and up to the first galaxies in the Epoch of Reionization (z>6) on the following four core topics:

1. Conditions for star formation in galaxies and the role of stellar feedback;

2. The relationship between star formation and chemical evolution;

3. The CGM and IGM role in shaping star formation activity in galaxies;

4. The role of AGN feedback in regulating star formation.

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Symposium Schedule

STScI **2024 SPRING SYMPOSIUM**

Link to the schedule spreadsheet:

https://docs.google.com/spreadsheets/d/1PbcN5T4SJgrTgxY9C8qbyyOQ7ORiI7HAsalCuHJ5R2U/edit?usp=sharing

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MONDAY, APRIL 15TH — VENUE: INN AT THE COLONNADE

TIME	*TITLE*	*SPEAKER*
12:00 PM	*Lunch at the "Inn at the Colonnade"*	
01:00 PM	*Welcome Message*	
	Session 1a: Conditions for star formation in galaxies and the role of stellar feedback	
1:15 PM	***Star Formation and Turbulence Across Cosmic Time***	***Blakesley Burkhart (invited)***
1:45 PM	**The Nature of Star Formation and Radiative Feedback in Dense Compact Starbursts**	***Shyam Menon***
2:00 PM	***Using galaxies at cosmic dawn as a laboratory for star formation physics***	***Rachel Somerville***
2:15 PM	***Metallicity Dependence of Pressure-Regulated Feedback-Modulated Star Formation: a TIGRESS view***	***Chang-goo Kim***
2:30 PM	***Where Does all the Feedback Go?***	***Bruce Elmegreen***
2:45 PM	*Coffee Break*	
3:15 PM	***ALMaQUEST tests the importance of dynamical equilibrium pressure in regulating star formation.***	***Sara Ellison***
3:30 PM	***Decoding star formation across times and timescales with JWST and CAMELS***	***Kartheik Iyer***
3:45 PM	***Probing stochastic star formation in the first galaxies with JWST***	***Viola Gelli***
4:00 PM	***Metallicity of galactic winds***	***Magdalena Hamel Bravo***
4:15 PM	***New Insight into Stellar Feedback at Extremely Low Metallicity from the Only HII Region in Leo P***	***Grace Telford***
4:30 PM	*Discussion 1*	
5:00 PM	*Welcome Reception at the "Inn at the Colonnade"*	

TIME	*TITLE*	*SPEAKER*
8:30 AM	*Breakfast*	
	Session 1b: Conditions for star formation in galaxies and the role of stellar feedback	
9:00 AM	***Multi-Scale Star Formation and Feedback in Nearby Galaxies (Session 1b - invited)***	***Daniela Calzetti (invited)***
9:30 AM	***Low Metallicity Star Formation in the Local Universe with JWST***	***Alec Hirschauer***
9:45 AM	**The 3.3 um PAH emitters population in the PHANGS-JWST galaxies**	***Jimena Rodriguez***
10:00 AM	***Spatially resolved star formation of galaxies in Cosmic noon from HST and JWST observations***	***Lu Shen***
10:15 AM	***Flash-Talks 1***	

- ***Christina Lindberg:*** *Dust around massive stars is agnostic to galactic environment: New insights from PHAT & BEAST*
- ***Alec Martin:*** *Properties of Giant Star-forming Clumps and their Host Galaxies Observed by HST and JWST*
- ***Daniel Maschmann:*** *PHANGS-HST catalogs for ~100,000 star clusters and compact associations in 38 galaxies*
- ***Chloe Neufeld:*** *The Paschen-alpha Star Forming Sequence at z~1-2*
- ***Jorge Pineda:*** *Far-infrared spectral lines as tracers of the impact of stellar feedback*
- ***Kaila Ronayne:*** *7.7µm PAH Star Formation Rate Calibration with JWST MIRI*
- ***Guochao Sun:*** *The Unsettled Youth of Galaxies: Understanding Bursty Star Formation in Galaxies at Cosmic Dawn*

10:30 AM	*Mid-Morning Coffee Break*	
11:00 AM	***Resolving high-redshift star-forming regions at 10-100s pc resolution with JWST***	***Adelaide Claeyssens***
11:15 AM	***Revealing the parsec-scales details of a z=6 star-forming system with NIRCam+NIRSpec***	***Matteo Messa***
11:30 AM	***JWST Emission Line Survey: Probing emission-line galaxies in to the Epoch of Reionisation***	***Corey Pirie***
11:45 AM	***Do EELGs from low to high-z make or break what we know about Star Formation & ISM conditions?***	***Ali Ahmad Khostovan***

12:00 PM	*Discussion 2*	
12:30 PM	*Lunch Break*	
	Session 2a: The relationship between star formation and chemical evolution	
1:30 PM	***TBD (Session 2a - invited)***	***Danielle Berg (invited)***
2:00 PM	***Pinning down the multi-phase mixing of metals within star-forming galaxies***	***Bethan James***
2:15 PM	***Robust Chemical Enrichment from Optical and Infrared Emission Lines in the Era of JWST and ALMA***	***Yuguang Chen***
2:30 PM	***Connecting Mass, Metallicity, and Star-formation Rate for the Lowest Mass Galaxies at Cosmic Noon***	***Mitchell Revalski***
2:45 PM	***Flash-Talks 2***	

- ***Juan Alfonzo: Katachi (形) :*** *Decoding the Imprints of Past Star Formation on Present Day Morphology in Galaxies*
- ***Javier Ballesteros-Paredes:*** *Gravity or turbulence? Understanding the star formation law from molecular clouds to galaxies.*
- ***Logan Jones:*** *Wind and Fire: Resolving the multi-phase ISM of M83 with JWST*
- ***Valentina La Torre:*** *Star Formation Rate Estimation using Self-Organizing Maps for Large Dataset Surveys*
- ***Michael Romano:*** *The imprint of star-formation-driven outflows on the evolution of nearby dwarf galaxies*
- ***Peter Zeidler:*** *Star formation at low metallicities – from massive OB stars to YSOs in the SMC star cluster NGC 602*

3:00 PM	*Mid-Afternoon Coffee Break*	
3:30 PM	***Resolved Metallicity and Stellar Population Maps at z~1-2: Implications for Stellar Models***	***Grace Olivier***
3:45 PM	***Temperature-based gas-phase abundance patterns at Cosmic Noon from ultradeep JWST/NIRSpec spectra***	***Ryan Sanders***
4:00 PM	***Accurate metallicities of the ionized gas from low to high redshift with a new approach to photoionization models***	***Alessandro Marconi***
4:15 PM	***Interpreting gas metallicity gradients at high-z using cosmological zoom in simulations***	***Ayan Acharyya***
4:30 PM	***Does the Fundamental Metallicity Relation Evolve with Redshift***	***Alex Garcia***
4:45-5:15 PM	*Discussion 3*	
6:30 PM	*Baseball Game at Camden Yards*	

TIME	*TITLE*	*SPEAKER*
8:30 AM	*Breakfast*	
	Session 2b: The relationship between star formation and chemical evolution	
9:00 AM	***The relationship between star formation and chemical evolution***	***Chiaki Kobayashi (invited)***
9:30 AM	***Different regimes of star formation across cosmic time***	***Florent Renaud***
9:45 AM	***Near and Far: Modeling Chemical Evolution in the JWST Era***	***Mia Bovill***
10:00 AM	**Effects of Population III supernovae on the formation of the first enriched stars**	***Jennifer Mead***
10:15 AM	***Flash-Talks 3***	

- ***Valentina Abril Melgarejo:*** *Mapping multi-phase mixing of metals in Star Forming Galaxies*
- ***Laura Duffy:*** *Dust Attenuation of Star Forming Regions in Nearby Galaxies and the Swift+MaNGA Value Added Catalog*
- ***James Garland****: Characterizing Fine Metallicity Fluctuations Across Galactic Structures with SIGNALS*
- ***Ava Polzin****: Molecular gas in low metallicity galaxies and its implications for star formation*
- ***Brian Welch:*** *Physical Conditions of Gravitationally Lensed Galaxies with JWST*
- ***Karla Arellano Cordova:*** *Chemical Evolution Near and Far: Abundance Patterns in the JWST Era*
- ***Laurie Rousseau-Nepton:*** *SIGNALS: The Star-formation, Ionized Gas, and Nebular Abundances Legacy Survey*

10:30 AM	*Mid-Morning Coffee Break*	
11:00 AM	***3D imaging spectroscopy and cosmological simulations to trace the chemical history of galaxies***	***Kathryn Grasha***
11:15 AM	***Nitrogen-enriched, Highly Pressurized Nebular Clouds Surrounding a Super Star Cluster at Cosmic Noon***	***Massimo Pascale***
11:30 AM	***Unveiling Cosmic Dust Chronicles at early epochs with the James Webb Space Telescope***	***Ambra Nanni***
11:45 AM	***The impact of star formation and stellar feedback models on the properties of low mass galaxies about Star Formation & ISM conditions?***	***Anna Engelhardt***
12:00 PM	*Discussion 4*	

12:30 PM	*Lunch Break*	
	Session 3a: The CGM and IGM role in shaping star formation activity in galaxies	
1:30 PM	***The role of CGM and IGM in shaping star formation activity in galaxies***	***Sanchayeeta Borthakur (invited)***
2:00 PM	***The Cool CGM of the Large Magellanic Cloud***	***Sapna Mishra***
2:15 PM	***Hot Gas Properties of Local Starburst-Driven Outflows***	***Sebastian Lopez***
2:30 PM	***Joint ALMA+JWST analysis of the circumgalactic medium of MACS1931-26***	***Laya Ghodsi***
2:45 PM	***Flash-Talks 4***	

- ***Eshita Banerjee:*** *The Circumgalactic medium of Lyman-alpha emitters at z~3.3*
- ***Alexander Beckett:*** *Tracing metals in and around galaxies with the MUSE Ultra Deep Field*
- ***Seery Chen:*** *Imaging the Circumgalactic Medium with the Dragonfly Spectral Line Mapper*
- ***Sophia Flury:*** *Stellar Feedback Clears the Path to Cosmic Reionization*
- ***Will Liu:*** *Revealing cosmic systems: exploring giant, optically emitting, circumgalactic nebulae*
- ***Allison Man:*** *A kpc-view of the CO, [CI] and dust emission in and around a starbursting AGN-host galaxy at z~2.6*
- ***Grecco Oyarzun:*** *The baryon cycle in HI-selected galaxies at z~2*
- ***Diane Salim:*** *Setting analytic prescriptions ablaze: Machine-Learnt Star-formation laws with FIRE-2*

3:00 PM	*Mid-Afternoon Coffee Break*	
3:30 PM	***Spatial distributions and kinematics of z~0.35 star-forming and confirmed LyC (non-) leakers***	***Floriane Leclercq***
3:45 PM	***Enrichment of the multi-phase circumgalactic medium in dwarf galaxies from CUBS and MUSEQuBES***	***Sean Johnson***
4:00 PM	***The stellar populations of gas-rich absorbing galaxies: the essential link to the baryon cycle***	***Ramona Augustin***
4:15 PM	***Galaxy local environments and star formation burstiness in low-mass high-z galaxies***	***Yoshihisa Asada***
4:30 PM	***The evolution of intervening metal absorbers at 2<z<7 using E-XQR-30***	***Alma Sebastian***
4:45-5:15 PM	*Discussion 5*	
5:15 PM	*SDAS (beer&snacks)*	

TIME	*TITLE*	*SPEAKER*
8:30 AM	*Breakfast*	
	Session 3b: The CGM and IGM role in shaping star formation activity in galaxies	
9:00 AM	***The role of the circumgalactic and intergalactic medium in galaxy formation***	***Freeke van de Voort (invited)***
9:30 AM	***Bridging Observations and Simulations of the Resolved CGM with the Dragonfly Spectral Line Mapper***	***Imad Pasha***
9:45 AM	***Circumgalactic medium at high-z: connecting cosmological filaments with central galaxies***	***Da Bi***
10:00 AM	***Arkenstone: Simulating CGM-based Star Formation Regulation with High Specific Energy Outflows***	***Greg Bryan***
10:15 AM	***Flash-Talks 5***	

- ***Dylan Benton:*** *Density vs. Destiny: the Lifecycle of Star-Forming Gas in FIRE-3*
- ***Cody Carr:*** *Testing our ability to measure outflow properties and their impact on star formation with FIRE*
- ***Sayak Dutta:*** *MUSEQuBES: A study of gas and metals around low-redshift galaxies*
- ***Julianne Goddard:*** *Effects of Active Galactic Nuclei Feedback on Galactic Morphology (Goddard, Shlosman, Romano-Diaz)*
- ***Celine Greis:*** *HI's Role in regulating global and local SFR in the Virgo Cluster*
- ***Chris Mihos:*** *Star Formation at the Lowest Densities: Starbursts in Diffuse Environments*
- ***Keerthi Vasan:*** *Resolved studies of galactic outflows at Cosmic Noon*

10:30 AM	*Mid-Morning Coffee Break*	
11:00 AM	**Expandable Galactic Atmospheres and the Physics of Galaxy Self-Regulation**	***Viraj Pandya***
11:15 AM	***Regulating Star Formation with a Hot Circumgalactic Medium***	***Chris Carr***
11:30 AM	***Growing Pains: Disruption from Superbubble Feedback Across z~3-0 in Simulated Galaxies***	***Lori Porter***
11:45 AM	***The timescales and drivers of Milky Way satellite quenching***	***Charlotte Christensen***
12:00 PM	*Discussion 4*	
12:30 PM	*Lunch Break*	
1:30 PM	***Overview on Habitable World Observatory***	***Jason Tumlison***

Session 4a: The role of AGN feedback in regulating star formation

2:00 PM	***The role of AGN feedback in regulating star formation***	***Giovanni Cresci (invited)***
2:30 PM	***Extended Dusty Star Formation Halfway Back to Cosmic Noon***	***Jason Young***
2:45 PM	***Insights into z>6 SFHs and early cosmic chemical evolution from z>3 massive quiescent galaxies***	***Themiya Nanayakkara***
3:00 PM	*Mid-Afternoon Coffee Break*	
3:30 PM	***Flash-Talks 6***	

- ***Xiaoyang Chen:*** *Failed AGN feedback? -- Molecular reservoirs are not severely affected by extreme AGN ionized-wind*
- ***Allison Erena***
- ***Mason Footh:*** *Dual AGN fractions in galaxy mergers and implications for SMBH growth*
- ***Francesco Salvestrini:*** *The coevolution of star formation and SMBH accretion at Cosmic noon*
- ***Yang Sun:*** *Evolution of Gas Flows along the Starburst to Post-Starburst to Quiescent Galaxy Sequence*
- ***Arjun Suresh:*** *Radio-AGN activity is not a direct function of host galaxy star formation rate*
- ***Shenli Tang:*** *Rich and diverse molecular gas environment of dual quasars viewed by ALMA*

3:45 PM	***The impacts of AGN feedback in a local galaxy: the case of NGC7469 from the eyes of JWST-NIRSpec***	***Marina Bianchin***
4:00 PM	***NIRCam Observations of NGC 4258 - A Nearby Galaxy to Study Star Formation History on Multiple Scales***	***Isha Nayak***
4:15 PM	***The molecular view of AGN feedback at cosmic noon: do AGN gas-deplete their hosts?***	***Elena Bertola***
4:30 PM	***MIRI-MRS Insights: Unraveling the Kinematics of LIRGs at z~0.6***	***Miriam Eleazer***
4:45-5:15 PM	*Discussion 6*	
6:30 PM	*Social Dinner (Inn at the Colonnade)*	

FRIDAY, APRIL 19TH VENUE: MULLER AUDITORIUM, STSCI

TIME	*TITLE*	*SPEAKER*
8:30 AM	*Breakfast*	

Session 4b: The role of AGN feedback in regulating star formation

9:00 AM	***The role of AGN feedback in regulating star formation***	***Daniel Anglés-Alcázar (invited)***
9:30 AM	**The Role of AGN Feedback in the CAMELS Simulations in Regulating SFR and SMBH Seeding**	***Megan Tillman***
9:45 AM	***Modelling the impact of AGN-driven winds on galaxy sizes***	***Rachel Cochrane***
10:00 AM	***The z=0 Distribution of Star Formation in TNG100 Galaxies: Intrinsic and Environmental Factors***	***Bryanne McDonough***
10:15 AM	***Flash-Talks 7***	

- ***Kristen Garofali:*** *Detecting Accreting Black Holes in Dwarf Galaxies: Emission Line Diagnostics for the JWST Era*
- ***Felix Mirabel:*** *Black-hole positive feedback and galaxy formation in the early universe*
- ***Osase Omoruyi:*** *Powerful AGN Feedback Tied to Beads-on-a-String Star Formation in a Dynamically Active Galaxy Cluster*
- ***Sachithra Weerasooriya:*** *The Curious Case of Centaurus A*
- ***Michaela Hirschmann*** *(virtual)**:** Which processes can quench star formation in massive, high-redshift galaxies?*
- ***Giulia Tozzi*** *(virtual)**:** Fast & Furious: ionised winds faster in type-2 than in type-1 AGN at z~2*

10:30 AM	*Mid-Morning Coffee Break*	
11:00 AM	***Galaxy Quenching at the High Redshift Frontier with JWST***	***Asa Bluck***
11:15 AM	***Quenching via Tidal Removal of Cold Gas from Intermediate redshift Massive Post-starburst Galaxies***	***Vincenzo d'Onofrio***
11:30 AM	***AGN Feedback in Quiescent Galaxies at Cosmic Noon Traced by Ionized Gas Emission***	***Letizia Bugiani***
11:45 M	*Discussion 7*	
12:30 PM	*Lunch Break*	
1:00 PM-2:30PM	***WORKSHOP***	
	Exploring the PHANGS-HST+JWST+ALMA+MUSE Treasury of Nearby Galaxies	***David Thilker***
	Derivation of ISM properties	***Ryan Sanders***
2:30 PM	*Coffee Break*	
2:45PM-3:45PM	***WORKSHOP***	
	Hubble Advanced Science Products	***Travis Fischer***
3:45PM-4:30PM	***WORKSHOP***	
	Exploring ILLUSTRIS-TNG simulations to derive observationally-comparable Star formation rates and metallicities	***Bryanne McDonough***

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Symposium Abstracts

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2024 SPRING SYMPOSIUM

Invited Talks

Star Formation and Turbulence Across Cosmic Time

Blakesley Burkhart
Rutgers University

I will review the physical conditions of galaxies that set the star formation rates, efficiencies, and star-forming cloud lifetimes. At galactic scales, star formation rate activity correlates with the level of turbulence of the interstellar medium, which can be driven on kpc scales by both gravitational instability and supernova feedback. I will review self-regulation models and tests from recent numerical simulations, that will set the stage for later talks in this conference. Similarly, star formation efficiencies are known to be on average a few percent and are low due to the interplay of turbulent motions and immediate stellar feedback effects (radiation, jets and winds). I will review recent work corroborating this picture and also show when this picture might 'fail'' in extreme high surface density environments, e.g. at high redshift. Finally, I will discuss the effects of feedback in setting the lifetimes of star-forming clouds and present an outlook to near-term and far-future observatories (HWO) for testing current models of cloud lifetimes.

Multi-Scale Star Formation and Feedback in Nearby Galaxies

Daniela Calzetti
Dept. of Astronomy, University of Massachusetts

The ability to trace star formation and stellar feedback hinges on the ability to measure star formation rates and to link the small and large scale effects of feedback back to the stellar populations that produce them. I will provide a short review of the current status in these two key areas that together regulate star formation and create the complex multiphase ecosystem of galaxies. The future NASA flagship Habitable Worlds Observatory will build on what HST and JWST have been contributing in these areas, and provide key UV capabilities to trace the gas flowing and out of galaxies to finally link it to the star formation within the galaxies.

Title TBD

Danielle Berg
The University of Texas at Austin

[Abstract TBD]

The relationship between star formation and chemical evolution

Chiaki Kobayashi
University of Hertfordshire

During the Big Bang, only light elements can be formed, carbon and heavier elements (`metals' in astronomy) are formed in stars and ejected in interstellar medium when they die. Iron-peak elements are produced by binaries - Type Ia supernovae. Elements heavier than iron (such as gold) can be produced by neutron star mergers, although they alone cannot explain the observed ``r-process'' elements in the Milky Way. The metallicity of galaxies (both for stellar population and gas-phase) increases due to star formation but is modified by gas accretion, stellar migration, and by feedback from supernovae and active galactic nuclei. Hence, chemical composition of stars and gas in a galaxy evolve differently across cosmic time. Overall, because of the short timescale of star formation and the high efficiency of chemical enrichment, the metallicity is higher in more massive galaxies (leading to the mass-metallicity relation) and at the centre of galaxies (causing metallicity radial gradients). Cosmological, hydrodynamical simulations including detailed chemical enrichment (chemodynamical simulations) can successfully reproduce a number of observations at the current epoch, but not at higher redshifts, which is probably due to our incomplete understanding of feedback. Moreover, elemental abundances of external galaxies provide mode detailed constraints; the unexpected elemental-abundance ratios detected by the James Webb Space Telescope at very-high redshifts indicate stochastic star formation in the early Universe. It is necessary to reproduce elemental abundances in order to constrain star formation history of galaxies.

The role of CGM and IGM in shaping star formation activity in galaxies

Sanchayeeta Borthakur
Arizona State University

The circumgalactic medium is the connection between the star-forming disks and the rest of the Universe. The flow of gas through the CGM is critical for supporting and regulating star formation. In this talk, I'll discuss a variety of observational signatures of gas flows that provide clues to how the disks of galaxies might be fed and how the feedback from star formation can impact the CGM and the IGM that will ultimately regulate star formation and distribute metals in the CGM and the IGM. I'll also talk about the potentially transformative science that the Habitable World Observatory (HWO) can enable in the field of CGM/IGM and discuss the required HWO design specifications to achieve that.

The role of the circumgalactic and intergalactic medium in galaxy formation

Freeke van de Voort
Cardiff University

In this review I will summarise some key aspects of the large role the gas around galaxies plays in feeding the interstellar medium and regulating star formation. Galaxies are shaped by external processes, such as gas accretion and galaxy mergers, as well as internal processes, such as star formation and feedback-driven outflows. All of these processes are intimately connected: outflows do not just eject gas from galaxies, but also prevent gas from accreting in the first place. Yet outflows also pollute the circumgalactic gas with metals, resulting in higher cooling rates and thus higher gas accretion rates. By changing the properties of the halo gas, the galaxies themselves are changing the fuel supply for their own future star formation. Only fairly recently have cosmological, hydrodynamical simulations succeeded in creating realistic galaxies with correct masses, sizes, and star formation rates. This is primarily achieved by calibrating the ill-constrained parameters of feedback models which eject low angular momentum gas. However, similar galaxy populations matching observations can emerge from very dissimilar simulations, because the feedback implementations are degenerate. Because the simulations are primarily tuned to galaxy observables at low redshift, studying the circumgalactic medium and studying galaxies at higher redshift can help break some of the degeneracies.

The role of AGN feedback in regulating star formation

Giovanni Cresci
INAF - Osservatorio di Arcetri

Feedback from AGN is considered the main physical mechanism to quench star formation in galaxies, at least at the high mass end of the galaxy population. This feedback is believed to operate through powerful, massive outflows driven by the energy release operated by the AGN. However, while outflows are ubiquitous in AGN, their origin, properties and impact on host galaxies and physical properties are still poorly constraint.
I will review the results targeting AGN host galaxies from low to high redshift aimed at overcoming these limitations, showing the effects of AGN winds and jets on their host galaxies, and insights on the acceleration mechanisms of these winds. Finally, I will briefly discuss the challenges in selecting AGN at the high-z and low metallicities probed by JWST.

The role of AGN feedback in regulating star formation

Daniel Anglés-Alcazar
University of Connecticut

Active Galactic Nuclei (AGN) feedback in the form of radiation, winds, and jets powered by gas accretion onto supermassive black holes (SMBHs) likely plays a key role in the formation and evolution of galaxies. I will review recent progress in our understanding of the role of AGN feedback in regulating star formation in galaxies and driving the observed SMBH-galaxy connection from the point of view of cosmological hydrodynamic simulations and how these can be used to interpret observations across cosmic time.

Contributed Talks

The Nature of Star Formation and Radiative Feedback in Dense Compact Starbursts

Shyam Menon
Rutgers University/Flatiron Institute

The formation of stars in galaxies are largely controlled by its competition with feedback from massive stars, with pre-supernova feedback playing a crucial role in this context. There has been significant progress in quantifying this competition in conditions resembling weakly star-forming galaxies such as the Milky Way. However, the nature of star formation and feedback in highly dense, compact, dust-obscured environments -- such as encountered in IR-bright galaxies in the local, and more commonly higher redshift, Universe -- and its implications are yet to be fully explored. This regime result in starbursts that form young massive, compact, super-star clusters, the feedback from which could have important dynamical consequences on their host galaxies. Moreover, these conditions resemble those of proto-globular clusters that are now being detected with gravitational lensing. In this talk, I will present insights obtained from state-of-the-art radiation-hydrodynamic numerical simulations of star cluster formation in this regime. I will specifically highlight the aspects of star formation and feedback unique to this regime: the high star formation efficiencies achieved, the crucial role of radiation pressure on dust grains and outflows they launch, how these star clusters could be important contributors to reionization, and how a top-heavy IMF expected at high redshifts would change these outcomes. I will also connect how these findings can provide crucial insights in explaining the surprising excess of luminous massive galaxies at Cosmic Dawn detected by JWST.

Using galaxies at cosmic dawn as a laboratory for star formation physics

Rachel Somerville
Center for Computational Astrophysics

Molecular cloud scale simulations show that stellar feedback becomes weak and star formation efficiency skyrockets in high density, low metallicity environments. This has also been seen in local observations of "extreme" environments such as super star clusters. However, cosmological galaxy formation simulations typically hard-wire in low SF efficiency and strong stellar driven winds, guided by observations of star formation in "typical" environments and calibrated to reproduce average global galaxy properties in the nearby Universe. These simulations universally failed to predict the abundant population of UV luminous galaxies at ultra-high redshift ($z>10$) that JWST has recently revealed. I will show that we expect highly efficient star formation and weak stellar feedback to be ubiquitous in the early Universe due to the much higher typical ISM surface densities, and will present theoretical predictions from semi-analytic models with updated star formation and feedback recipes motivated by the cloud-scale simulations, that demonstrate the consequences for early galaxy formation. Our new model is able to account for the observed numbers of galaxies up to $z\sim13$-15 from current JWST observations, and makes testable predictions for future imaging and spectroscopic observations with JWST and other facilities.

Metallicity Dependence of Pressure-Regulated Feedback-Modulated Star Formation: a TIGRESS view

Chang-Goo Kim
Princeton University

Galactic star formation is inefficient due to feedback mechanisms that offset cooling and turbulence dissipation, upholding the disk's total pressure to avert catastrophic gravitational collapse. This presentation focuses on unraveling the co-regulation of star formation rates (SFRs) and the ISM, elucidating their connection to metallicity via the pressure-regulated, feedback-modulated star formation theory.

Introducing the TIGRESS-NCR (Non-equilibrium Cooling and Radiation) numerical framework, we showcase its prowess in solving radiation-magneto-hydrodynamics equations within local galactic patches with uniformly high resolution. Addressing supernova feedback with resolved Sedov stages and employing adaptive ray tracing for both ionizing and non-ionizing UV radiation feedback, the framework explicitly treats the main feedback route accurately. Furthermore, the coupling of UV radiation, cosmic ray ionization rates, and photochemical reactions ensures the establishment of self-consistent heating and cooling rates. The holistic view provided by the TIGRESS-NCR simulation suite plays a pivotal role in calibrating the theory, offering insights into the complex roles of turbulent, thermal, and magnetic pressure components derived from the intricate interplay between feedback and the multiphase ISM.

I will present novel predictions regarding the relationship between SFRs and metallicity. Low metallicity systems, under fixed galactic conditions, facilitate the transfer of FUV radiation, resulting in more efficient photoelectric heating and subsequently demanding lower SFRs. This shift in the thermal and non-thermal pressure balance causes systematic variations in the ISM phase distribution, promising unique signatures for future multiwavelength observations.

Where Does all the Feedback Go?

Bruce Elmegreen
Retired

Theories for the regulation of star formation by feedback have two forms: (a) control of ISM turbulence and therefore pressure, disk thickness and midplane density, which, in turn, controls the collapse rate for gas on a large scale, and (b) GMC breakup, which controls the efficiency of star formation on a small scale. Both are likely to be important. For (b), feedback energy is mostly deposited locally, and large-scale turbulence needs a contribution from other sources, such as Toomre-Q regulation by gravitational instabilities and spiral-arm streaming motions. In two previous papers, we examined 36 dwarf galaxies and 10 spirals, showing that HI turbulent velocities on scales of several hundred pc do not increase in star-forming regions. This result supported similar observations by Stilp et al. (2013) and L.C.

Hunter et al. (2022), who found that increased turbulence follows star formation by 50-100 Myr. Here we search for local correlations between molecular gas turbulence and SFR using PHANGS data (J. Sun, A. Leroy, et al. 2020-2023). In fact, we find a correlation between local GMC velocity dispersion and local SFR, unlike for HI, but there is no correlation with the local GMC virial parameter. SFR correlates most directly with molecular mass, and mass correlates with velocity dispersion via Larson's relation for virialized clouds. There is still no clear evidence for increased turbulence on ~100 pc scales resulting from active star formation. Massive-star feedback in young regions is apparently limited to GMC heating, ionization and compression into slow-moving structures.

ALMaQUEST tests the importance of dynamical equilibrium pressure in regulating star formation.

Sara Ellison
University of Victoria

The pressure-regulated feedback modulated (PRFM) theory of star formation posits that the pressure in the galactic interstellar medium is balanced by feedback from star formation. As a result, the theory predicts a tight, almost linear, relation between dynamical equilibrium pressure and star formation rate. Indeed, previous surveys that measure gas and star formation in normal star-forming galaxies on ~kpc scales have found excellent agreement with PRFM model predictions. However, the PRFM theory has yet to be tested in a diverse sample of galaxies that includes both starburst and quenching galaxies. The extended ALMA-MaNGA QUEnching and STar formation (ALMaQUEST) sample, which includes mergers, starbursts and green valley galaxies, offers the ideal opportunity to more fully test the PRFM model. In this talk, I will present new results on the resolved dynamical equilibrium pressure (rPDE) relation for ~20,000 kpc-scale spaxels in the extended ALMaQUEST sample. We find that, in main sequence galaxies, the rPDE relation does indeed agree with the PRFM model, in agreement with previous results. However, in starbursts and green valley galaxies, the data clearly deviate from the PRFM model. I will also show that an alternative model, that includes the effect of radial motions, can reproduce the data, demonstrating that additional sources of turbulence are required to fully describe the data. Despite the deviation from the PRFM-predicted rPDE relation in the ALMaQUEST sample, we use a random forest analysis to demonstrate that dynamical pressure equilibrium is nonetheless a far better predictor of star formation than either the stellar mass or molecular gas mass surface densities. Our results indicate that the rPDE relation is therefore more `fundamental' than either the resolved Kennicutt-Schmidt or the resolved star forming main sequence.

Decoding star formation across times and timescales with JWST and CAMELS

Kartheik Iyer
Columbia University

The star formation histories of galaxies hold imprints of the physical processes that regulate star formation across a range of timescales, ranging from small-scale fluctuations caused by the creation and destruction of GMCs to galaxy-wide events triggered by mergers and gas accretion. In particular, stellar and AGN feedback play a critical role in regulating star formation in galaxies. However, quantifying their precise signatures in the SFHs of galaxies remains challenging, coupled with observational challenges in constraining SFHs from multiwavelength observations. In this talk, I will outline (i) how non-parametric SFH reconstruction methods (Dense Basis; Iyer et al. 2019) can be applied to observations from HST and JWST to robustly reconstruct SFHs across a range of masses and redshifts, (ii) how these SFHs can then be analyzed in the context of an analytical model (GP-SFH; Iyer & Speagle et al. 2024) to constrain the timescales over which star formation rates are correlated and tie them to the physical mechanisms responsible, and finally (iii), how observational SFH signatures can be coupled with suites of cosmological simulations like CAMELS to constrain the strength of stellar and AGN feedback across different galaxy populations.

Probing stochastic star formation in the first galaxies with JWST

Viola Gelli
Cosmic Dawn Center (University of Copenhagen)

JWST has opened a new chapter in our understanding of early star formation by unveiling a surprising number of luminous galaxies at z>10 and also detecting the first quenched low-mass galaxies in the Epoch of Reionization. The coexistence of these extreme sources suggests highly time-variable star formation in the early Universe, raising critical questions: is star formation more stochastic at higher redshifts, and if so, why? I will discuss two complementary approaches to explore the nature of high-z galaxy stochastic star formation.

Firstly, cosmological simulations reveal several galaxies in temporary quiescent states at z>6, prevalent at low masses (M* < 10^(8.3) Msun). Detecting these quiescent galaxies provides direct proof of bursty high-z star formation. I will present a comparison with the first two z>5 low-mass quenched galaxies observed by JWST, and show that internal fast feedback processes, such as radiation-driven winds from young stars or AGN, must be already at play, on top of supernovae, to explain their SEDs.

Secondly, I will present a novel method for measuring the stochasticity of star formation from observations of high-z star-forming galaxies. Using a semi-analytical modelling approach, I will show how the distribution of galaxy properties, as measured from JWST photometry, can be used to infer the scatter in SFR as a function of halo mass. I will discuss the implications on the observed luminosity functions and whether the scatter of the SFR is driven by star formation efficiency or halo mass assembly.

Metallicity of galactic winds

Magdalena Hamel Bravo
Swinburne University

The metal enrichment from outflows is critical to the chemical enrichment of galaxies and the CGM. The so-called metal-loading in outflows is a direct input into any realistic simulation of galaxy evolution, yet direct observations of the metal-loading factor for warm gas are almost completely lacking from the literature. I will discuss ground-breaking efforts from the DUVET project, using deep IFU Keck/KCWI data, to measure the metallicity in outflows. We observe the very faint [OIII] 4363 auroral line, a robust metallicity tracer, in two low-metallicity starbursting galaxies. I present gas-phase metallicity map and estimate the metal loading of the outflowing gas. I will compare the metal-loading of these galaxies to results from absorption line analysis and to recent simulations of metal-enrichment in winds. One of our targets, NGC 1569, is close enough to allow spatial resolution of 20 pc. In this galaxy I study small-scale variation the T_e and the metallicity in the disk and outflow. I discover a high-metallicity region surrounding SSC-B, which I will argue that this is a result of GMC destruction via feedback processes. I will present recipes for finding such structures in nearby galaxies. Overall, my work shows how deep IFU observations are able characterise the flow of metals from the scales of star clusters to the winds of gas that regulate star formation and the baryon cycle.

New Insight into Stellar Feedback at Extremely Low Metallicity from the Only HII Region in Leo P

Grace Telford
Princeton University

Feedback from low-metallicity massive stars regulates star formation in dwarf galaxies both locally and at high redshift. However, spectra of individually resolved O stars below 20% solar metallicity are very rare, leaving theoretical models of their stellar winds and ionizing fluxes unconstrained. In this talk, I will present HST/COS far-ultraviolet and Keck/KCWI optical spectra of the only known O star in the nearby, extremely metal-poor galaxy Leo P (3% solar metallicity) and the HII region that it powers. The COS observations reveal that the star is a fast rotator driving a weak stellar wind, providing the first empirical support for theoretical expectations at this metallicity. These properties imply higher ionizing photon production than would be predicted by the stellar population synthesis models most commonly used to interpret observations of the metal-poor, high-redshift galaxies now being routinely observed by JWST. Finally, I will show that the shape of the star's ionizing spectrum is tightly constrained by the observed nebular emission lines in the KCWI spectrum of its surrounding HII region. The combined power of FUV and optical spectroscopy enables a unique test of stellar models at the very low metallicities relevant for modeling feedback processes in early galaxies and their contribution to cosmic reionization.

Low Metallicity Star Formation in the Local Universe with JWST

Alec Hirschauer
Space Telescope Science Institute

We present an investigation of star-forming populations in nearby, metal-poor systems with JWST NIRCam and MIRI. These observing programs were designed to better characterize the star-formation mechanisms of early Universe like systems, in accessible conditions analogous to cosmic noon ($z \sim 1.5$-2), when such activity peaked. Our programs observed four local star-forming systems over a range of enrichment levels, including N79 in the LMC ($Z \approx 0.5\ Z_\odot$), NGC 346 in the SMC ($Z \approx 0.3\ Z_\odot$), NGC 6822 ($Z \approx 0.2\ Z_\odot$), and I Zw 18 ($Z \approx 0.03\ Z_\odot$), at a variety of wavelengths, providing spatially-resolved photometry of IR-bright sources at photometric depths over 10 magnitudes below Spitzer and 2 magnitudes below HST at comparable wavelengths. Photometry is accomplished using the software package

StarbugII, which was developed for JWST imaging of crowded fields and complex backgrounds. With color-magnitude diagrams, we identify populations of young stellar objects and characterize the full populations of young stars, down to masses as low as ~0.1 $M_\odot$, the lowest yet found in extragalactic systems. We find evidence for the presence of dust required to create rocky planets even at low metallicities, allowing for their formation earlier than previously expected, and explore the demographics of newly-forming super star clusters. Through spectral energy distribution model fitting, we measure radii, temperatures, luminosities, and masses of interesting stellar sources. In addition, with MIRI/MRS we find a variety of important spectral features, including neutral hydrogen recombination associated with extragalactic protostars for the first time.

The 3.3 um PAH emitters population in the PHANGS-JWST galaxies

Jimena Rodriguez
Space Telescope Science Institute

The earliest stages of star and cluster formation occur inside dense cocoons of gas and dust that conceal their presence at optical wavelengths. Thanks to the unparalleled infrared capabilities of JWST, we now venture beyond the Magellanic Clouds, and obtain unprecedented ~10 pc resolution observations of dust-obscured star formation sites. Our early results from PHANGS-JWST suggest that 3.3μm PAH emission is an indicator of star clusters still in an dust embedded phase. Here we expand our study to the full 19 galaxies sample of the PHANGS-JWST Cycle 1 Treasury Survey. We present the properties of compact objects exhibiting 3.3μm PAH emission. Our analysis reveals that they are predominantly located within dust lanes, spiral arms, inner and outer rings, and central regions of galaxies. We find that 50-70% of the 3.3μm PAH emitters have concentration indices comparable to star clusters. Moreover, 20-60% of emitters are detectable in optical HST bands, where the detection rate anticorrelates with the strength of the PAH emission. PAH emitters are also frequently associated with Hα emission. A comparison with PHANGS-HST catalogs derived from optical observation suggests a rapid decline in PAH emission in ~2Myr, which provides additional evidence that the embedded phase is short, and feedback mechanisms prior to the onset of supernovae are important. The limited overlap between the HST optical cluster catalogs and PAH emitters, indicates that our JWST studies may significantly increase the census of the youngest clusters from PHANGS-HST.

Spatially resolved star formation of galaxies in Cosmic noon from HST and JWST observations

Lu Shen
Texas A&M University

Tracking spatially resolved star formation in galaxies can provide insight into the quenching mechanism and galaxies' structural and size evolution. The James Webb Space Telescope (JWST) not only facilitates a systematic exploration of high redshift galaxies, but also enables a detailed study of the rest-frame mid-infrared (mid-IR) and the optical emission lines of galaxies at intermediate redshifts, which together provide valuable insights into the overall star formation processes. In this talk, I will present the spatially resolved H-alpha equivalent width (EW) maps for 19 galaxies at $0.6<z<2.2$ using JWST NIRISS WFSS observation from the

Next Generation Deep Extragalactic Exploratory Public (NGDEEP) Survey. The pixel-to-pixel H-alpha EW increases with increasing specific SFR and with decreasing age derived from 21-band SED fitting. While, the average resolved trend is slightly different from the relations derived from integrated fluxes of galaxies from the literature, suggesting complex evolutionary trends inside galaxies and galaxy-to-galaxy variation. We found the majority (84%) of galaxies have positive H-alpha EW radial profiles, in line with the inside-out quenching scenario. Comparing the distributions of H-alpha EW and specific SFR to the star formation history models as a function of galactocentric radius, the central region of galaxies (e.g., their bulges) have experienced, at least one, rapid star-formation episodes, which leads to the formation of the bulge, while their outer regions (e.g., disks) grow in a more steady state.

Resolving high-redshift star-forming regions at 10-100s pc resolution with JWST

Adelaide Claeyssens
Stockholm University

Distant galaxies present an irregular morphology dominated by compact sub-structures called "clumps". The physical properties of these systems remain relatively unexplored and their role in galaxy evolution is not clear. The first detections indicate that these clumps could be a major mode of star formation and morphological evolution of galaxies. However, resolving structures at 10-100s pc scales in high-redshift galaxies is hardly achievable with current telescopes even with space-based observations. Combining the unprecedented sensitivity and spatial resolution of JWST with the natural gravitational lens telescopes is the only way to reach sub-hundred pc resolutions necessary to resolve individual clumps and star clusters.

I will present the properties of the first statistical sample of distant JWST clumps obtained from NIRCam observations of strongly lensed galaxies in multiple galaxy cluster fields. The optical restframe, probed with the JWST, enables us to measure physical properties of >2000 star-forming clumps from z=1 to z=10. We derive clumps properties overlapping with massive star clusters properties in the local universe and compact star-forming regions. Comparing these results with the most recent hydrodynamical simulations of star-forming clumps and star clusters within galaxies, we can understand the physical processes involved in the formation and evolution of the clumps/clusters and their host galaxies: gas turbulence, stellar feedback, galaxy mergers and bulge formation. These studies show the potential of JWST observations for understanding the conditions of the formation and evolution of star-forming regions and star clusters in rapidly evolving galaxies.

Revealing the parsec-scales details of a z=6 star-forming system with NIRCam+NIRSpec

Matteo Messa
INAF-OAS Bologna

The JWST is opening the possibility of studying the build-up of the first galaxies with unprecedented details. I will present the study of a gravitationally lensed system at z=6.14, behind the cluster MACSJ0416: Initially observed as a wide Ly-alpha arc, the combination of NIRCam imaging and NIRSpec IFU (4 pointings, expt~18 hr) reveals a intensively star-forming system, dominated by ~10 compact clumps, with derived intrinsic sizes on the order of 1-10 pc, and (surface) densities of the order of thousands M*/pc^2, making them ideal candidates of proto-GCs. Many of those stellar clumps show very steep UV slopes (-3<beta<-2.5), hinting at extreme ionisation efficiencies; however, while some of those are surrounded by HII regions with large equivalent widths (EW>2000 A), others show a lack of nebular lines, possibly hinting at young objects deprived of gas or with non-negligible escape fractions. The compact clumps of the system are linked by a low-surface brightness (in UV and Optical) arc where also continuum-dark low-metallicity emitting regions are found. The entire system spans only few kpc in size, with the addition of a 15 kpc-separated companion compact (<100 pc) emitting source: the overall view of the system reveals how diverse and highly-structured high-z system can be and how their study will be fundamental to understand the build-up of the first galaxies.

JWST Emission Line Survey: Probing emission-line galaxies in to the Epoch of Reionisation

Corey Pirie
Institute for Astronomy, University of Edinburgh

The JWST Emission Line Survey (JELS) aims to identify and study ~1000 emission-line selected galaxies across cosmic time using the power of NIRCam narrow-band imaging. Our primary science driver is the detection of ~40 H-alpha emitters at redshift z>6, out to the Epoch of Reionisation. The H-alpha emission line is the best-calibrated star-formation indicator in the nearby Universe, and narrow-band surveys have mapped the evolution of H-alpha emitters out to the peak star-formation epoch at z~2. At higher redshift, samples of star-forming galaxies and estimates of the cosmic star-formation rate density are almost ubiquitously based on rest-frame UV observations; this single approach carries a high risk of systematic effects, both in the populations of galaxies selected and in their derived properties. In this talk, I shall share preliminary results from JELS which will foreshadow bigger results soon to come such as the first critical test of comparing the H-alpha derived star-formation rate density at z>6 to rest-UV measurements. In addition, I will discuss other science goals of the survey including: i) obtaining fainter H-alpha emitters at cosmic noon, z~2, and hence constraining the faint end of the luminosity function, ii) utilising NIRCam's remarkable angular resolution to measure the ionised gas structures of these galaxies to high-redshift (including other line-emitters such as [OIII] emitters at z=8.3) at sub-kpc resolution and iii) determine how the relationship between UV and ionised gas structures varies with host galaxy properties, in order to delineate the physical processes driving star formation at these redshifts.

Do EELGs from low to high-z make or break what we know about Star Formation & ISM conditions?

Ali Ahmad Khostovan
Rochester Institute of Technology

Extreme Emission Line Galaxies (EELGs) are characterized by high equivalent widths (EWs) and intense star-formation bursts. Past studies suggest these are low-z analogs of typical high-z star-forming galaxies. In the first part of my talk, I will present our recent results of a record breaking EELG at z = 0.8275 (EW_0([OIII]+Hb) ~ 3200A and strong [OIII]4363A) identified in the COSMOS Spectroscopic Archive that is more extreme than typical z > 6 SFGs currently observed with JWST. This source has a highly energetic, metal-poor, and dust-free ISM with high electron density & temperature, LyC escape, and no AGN activity. SFH reconstruction suggests a recent ~ 10 Myr burst with no significant past SF activity. The ionizing photon production efficiency (xi_ion) is also found to be higher compared to high-z galaxies. I will discuss how such sources can have implications for cosmic reionization and our understanding of SF and ISM conditions in extreme high-z SFGs. Motivated by these results, the second part of my talk will focus on preliminary results from our work on z ~ 7 – 9 [OIII] EELGs selected based on nebular excess in NIRCam/F444W COSMOS-Web imaging. EWs are inferred from CIGALE and are found to reach ~ 4000 – 6000A with recent SF bursts and inferred xi_ion > 10^26 erg-1 s-1 (not found in sizable numbers within current JWST studies). I will conclude my talk by showing how Roman and Euclid will target similar EELGs at cosmic noon in larger numbers given the wide area & deep coverage.

Pinning down the multi-phase mixing of metals within star-forming galaxies

Bethan James
STScI

Deciphering the interplay between metallicity, star-formation, and outflowing gas, both spatially within a system and globally with redshift, is of paramount importance for understanding galaxy formation and evolution. With this goal in mind, the treatment of metals as homogeneous distributions throughout star-forming galaxies (SFGs) is no longer acceptable. Chemical inhomogeneities have been detected in the ionized gas of numerous SFGs via spatially resolved studies, with large implications for star-formation and the flow of metals within and around galaxies, which I will demonstrate within this talk. However, metals exist in multiple phases and, at present, the spatial distribution of metals throughout the separate gas phases in SFGs remains unknown. Recent high-resolution galaxy-scale hydrodynamical simulations have made significant advancements, opening up crucial questions concerning mixing timescales and the presence of localized enrichment between the two gas phases. Answers can only be found by measuring both the neutral and ionized gas abundances along identical sightlines throughout nearby SFGs. In this talk we present new neutral gas abundances from UV spectroscopy with HST/COS from the The COS Legacy Archive Spectroscopic SurveY (CLASSY), covering 45 galaxies selected to span similar properties as those seen at high-z. When combined with ionized gas abundances of spatially matched spectra from optical SDSS spectra, this unique dataset provides the largest study of metals between two phases within SFGs. Determining whether metal abundance offsets exist between the two phases, across a range of HII region properties, enables an exceptionally detailed sampling of chemical mixing scenarios and enrichment mechanisms experienced in SFGs. The low metallicities and high SFRs of our sample make our findings applicable to both nearby and high-z SFGs. This remarkable study provides the first observational test of multi-phase abundance patterns in cosmological simulations of dwarf galaxies.

Robust Chemical Enrichment from Optical and Infrared Emission Lines in the Era of JWST and ALMA

Yuguang Chen
UC Davis

Gas-phase metallicity (e.g., O/H) and chemical enrichment patterns (e.g., N/O) are the most fundamental properties of galaxies, important for a number of basic interstellar medium (ISM) processes (e.g., gas fraction, star and dust formation), galactic outflow, and accretion. However, current metallicity measurements suffer from 20-40% systematic uncertainty. This uncertainty, known as the abundance discrepancy factor, is revealed by the disagreement between two "direct" measurement techniques. We have developed a method to directly measure temperature fluctuations, the most adopted explanation of the ADF by utilizing far-IR and deep optical IFU integral field spectroscopy. In two nearby HII regions, Mrk 71 and Haro 3, we provided the first direct temperature fluctuation measurements in O and N, and found that temperature fluctuations are insufficient to explain the ADF. We are expanding this test on a sample of ~20 HII regions. With the recent observations of z>6 galaxies in rest-optical and IR using JWST and ALMA, this sample will also provide a well-needed benchmark in the local universe to be compared with high-z galaxies.

Connecting Mass, Metallicity, and Star-formation Rate for the Lowest Mass Galaxies at Cosmic Noon

Mitchell Revalski
Space Telescope Science Institute

Understanding the connections between galaxy stellar mass, gas-phase metallicity, and star-formation rate (SFR) is critical for constraining models of galaxy evolution and enrichment of the CGM. Measuring these properties at the lowest masses and SFRs is especially crucial as heavy elements can more easily escape the shallow gravitational potentials of low mass galaxies; however, these systems are very faint and require deep observations to characterize. We use 90 orbits of HST WFC3 grism spectra and 150 hours of VLT MUSE spectroscopy of the MUSE Ultra Deep Field to extend the gas-phase mass-metallicity relation (MZR) at z ≈ 1-2 down to stellar masses of M ≈ 10^7.5 M⊙. Our sample reaches five times lower in stellar mass and SFR than previous HST and MUSE studies at these redshifts, and we find that galaxy metallicities decrease to log(O/H) + 12 ≈ 7.7 ± 0.1 (10% solar) at log(M/M⊙) ≈ 7.6, without evidence of a turnover at low masses. We validate our strong-line metallicities using the direct method for sources with [O III] λ4363 and [O III] λ1666 detections, finding excellent agreement between the techniques. The [O III] λ1666-based metallicities validate the results at z ~ 2.5, providing an anchor for strong-line calibrations at the peak of cosmic star-formation. At lower redshifts (z ~ 0.5) our sample reaches ~0.5 dex lower in SFR than current calibrations and we find enhanced metallicities that are consistent with extrapolating the MZR to lower SFRs if the low mass slope varies with SFR. These results reach the lowest masses and SFRs accessible with HST, providing a critical foundation for upcoming studies with JWST and Roman.

Resolved Metallicity and Stellar Population Maps at z~1-2: Implications for Stellar Models

Grace Olivier
Texas A&M University

Understanding what sources reionzied the universe is one of the major goals for JWST but so far the sources remain elusive and unknown. Using new observations from the TEMPLATES ERS program targeting two gravitationally lensed UV-bright galaxies at z~1-2, I will present highly resolved metallicity maps of these systems compared to resolved maps of the stellar populations from the far-UV. I will test whether the observed stellar populations are capable of reproducing the observed nebular structure, tightly constraining the production of ionizing photons. I will also compare the stellar and nebular metallicities to demonstrate the enhanced alpha abundances at this moderate redshift. My results on the stellar and nebular emission in these star-forming galaxies have implications for the relevance of low-metallicity stellar models at cosmic noon and beyond.

Temperature-based gas-phase abundance patterns at Cosmic Noon from ultradeep JWST/NIRSpec spectra

Ryan Sanders
University of Kentucky

I will present results from the AURORA survey based on ultradeep (24 hours on-source) JWST/NIRSpec multiobject spectroscopy of star-forming galaxies at z~2-4. With continuous coverage spanning 1-5 microns, these extremely deep spectra reveal a wealth of faint emission and absorption features spanning the rest-frame ultraviolet to near-infrared providing a comprehensive view of the stellar and ISM properties of high-redshift galaxies in a level of detail previously only available at z~0. A key science case enabled by these data is the determination of detailed gas-phase abundance patterns using the direct method based on temperature-sensitive auroral emission lines, of which we detect both auroral [OIII]4363 and [OII]7320,30 in many z>2 sources. I will present results on strong-line metallicity calibrations at high redshift, relationships between electron temperature in different ionic zones, ISM ionization state and physical conditions, and multi-element abundance patterns of O, N, S, Ne, Ar, and C in z>2 galaxies. These abundance patterns are interpreted through galaxy chemical evolution models that constrain star formation histories. These extremely deep spectra enabled by JWST/NIRSpec allow us to apply the gold-standard diagnostic tools used in local HII region studies to high-redshift galaxies in great detail for the first time, bridging the gap between local and early-universe investigations of gas-phase abundances.

Accurate metallicities of the ionized gas from low to high redshift with a new approach to photoioni

Alessandro Marconi
Department of Physics and Astronomy, Univeristy of Florence

The metallicity of the ionized gas provides important constraints on the star-formation and feedback history of galaxies such as those given by the mass-metallicity and fundamental metallicity relations. With the advent of JWST it is now possible to trace the evolution of gas metallicity up to the highest redshift. However, metallicity measurements are plagued by significant uncertainties: metallicity is estimated from ratios of strong lines which have been calibrated extensively in the local universe but they are still plagued by significant uncertainties it is not clear whether they are still valid at high redshift.

The Te-method is commonly used to "directly" estimate metallicities and is based on gas densities and temperatures from forbidden line ratios. It has been used for decades but has been developed when computational resources were extremely limited, hence it is based on very simplified assumptions. The accuracy reached by current spectroscopic measurements calls for more accurate approaches. I will present HOMERUN (Highly Optimized Multi-cloud Emission-line Ratios Using photo-ionizatioN), an innovative approach to photoionization modelling which allows to reproduce many observed line ratios from a wide range of ionization stages with an unprecedented accuracy of 10%. As in previous work, our approach is based on the weighted combination of multiple single cloud photoionization models, but the novelty is in the computation of the weights which are set by the observations. Our approach provides a significant improvement compared to existing models and allows accurate determinations of the metallicity of the ionized gas, regardless of whether one analyses a local or a high redshift galaxy spectrum obtained with JWST. I will present the results obtained from applying these models to different samples of HII regions, star forming galaxies and AGN at low and high-z showing, for instance, how we can estimate the average physical conditions of ionized gas in galaxies and how the Te-method can severely underestimate gas abundances.

Interpreting gas metallicity gradients at high-z using cosmological zoom in simulations

Ayan Acharyya
Johns Hopkins University

Regulating star-formation necessarily depends on regulating the flow of gas from which the stars would eventually form. The mechanisms that govern the complex gas flows within the galactic disk and across the disk-halo interface is therefore crucial ingredients for understanding the evolution of galaxies and their star-formation histories. An important diagnostic for such flows is the spatially resolved gas-phase metallicity distribution, including the metallicity gradient. Observations only ever capture a single snapshot of a galaxy's evolution, necessitating the need for time-domain simulations to interpret the evolution of those gradients.

Using the FOGGIE simulations we demonstrate that a high cadence (~few Myr) is indispensable for accurately tracking the metallicity gradient evolution, particularly at high-redshift (z). FOGGIE galaxies spend ~50% (~20%) of their time up to z=1 (z=0) outside the typical observational uncertainty away from the temporally smooth (~50 Myr) evolution -- which would be difficult to capture with lower cadence. Additionally, we present a novel, non-parametric method of quantifying the metallicity distribution which is free from geometric assumptions. Therefore, our method is less susceptible to systematic uncertainties from the lens-model reconstruction employed in several high-z observations.

We investigate how efficiently the our new method responds to metal-mixing stimuli, such as star-formation, mergers and outflows. Our models pave the way for interpreting upcoming JWST observations of high-z metallicity gradients.

Does the Fundamental Metallicity Relation Evolve with Redshift

Alex Garcia
University of Virginia

Understanding the relationship between stellar feedback and a galaxy's metal content is essential for unraveling the baryon cycle. The fundamental metallicity relation (FMR), a three-parameter correlation between stellar mass, gas-phase metallicity, and star formation rate, serves as a valuable tool for tracing the evolution of galactic gas dynamics across cosmic epochs. Surprisingly, previous studies indicate no redshift-dependence in the FMR up to $z\sim2.5$. However, recent observations from JWST challenge this view, suggesting evolution of the FMR in the early universe. We propose a framework to reconcile these discrepancies and shed light on the evolving nature of the FMR. We corroborate the JWST findings, identifying evidence of FMR evolution in the cosmological simulations Illustris, IllustrisTNG, and EAGLE. Additionally, we find the FMR is sensitive to variations in stellar feedback implementation between the different simulation models. We further predict that simulations incorporating burstier stellar feedback should have a much weaker FMR. These findings underscore the significance of the high-redshift FMR as a sensitive probe for delineating the underlying physics governing galaxy formation in the early universe and emphasize the need of high-redshift JWST observations.

Different regimes of star formation across cosmic time

Florent Renaud
Strasbourg Observatory

In the last decade, observations of local galaxies have revealed the importance of the kpc-scale environment in the formation and regulation of star forming regions. This is now being complemented by surveys at high redshift, in the more extreme conditions of stronger turbulence and lower metallicity in young galaxies. Yet, it remains unclear whether the process of star formation remains the same in these conditions, as a mere extrapolation of the well-studied conditions of nearby galaxies, or if a new regime must be invoked. In this talk, I will use a series of high resolution cosmological and isolated simulations to illustrate how disk settling, mergers, and the evolution of the gas fraction delineate different regime of star formation across cosmic time, along phases of galaxy evolution. I will explain how these differences leave distinct imprints in the chemical enrichment of the ISM and the composition of stellar populations, and how observational programs using the present and next generation of instruments, in the Milky Way and at high redshift, could help discriminating between scenarios of galaxy evolution.

Near and Far: Modeling Chemical Evolution in the JWST Era

Mia Bovill
University of Maryland

JWST observations have produced unprecedented observations of metal abundances during Cosmic Dawn. Understanding what these measured abundances tell us about chemical evolution during the first billion years requires modeling. Semi-analyic models (SAMs) are uniquely suited to explore the relatively unknown parameter space. We present modeled O and Fe abundances calculated with a new supernova feedback algorithm in the SAM Galacticus. Galacticus has been shown to simultaneously reproduce the properties of the Local Group dwarfs and high redshift star formation densities. As such we calibrate the modeled alpha/Fe abundances based on the Local Group dwarfs for two Type Ia supernova delay functions. We then provide predictions for current and upcoming JWST observations of O and Fe abundances at high redshift.

Effects of Population III supernovae on the formation of the first enriched stars

Jennifer Mead
Columbia University

As JWST probes deeper into the early universe, direct evidence for the first steps of chemical evolution is closer than ever before. The first supernovae from Population III stars lit the way for enriched star formation to occur. However, to understand how, when, and under what conditions the first enriched stars formed, it is necessary to understand how small numbers of Population III stars regulated the environment of star-forming regions in minihalos (~10^5 - 10^7 Msun). To do so, high-resolution star-by-star simulations are needed to resolve the mixing of gas on small scales and to properly model the effects of individual stellar feedback events. Aeos is a suite of high-resolution star-by-star cosmological hydrodynamic simulations that follow the formation of stars in minihalos up until z=14. By tracking 10 different metals formed through three different nucleosynthetic channels, Aeos follows the first steps of chemical evolution in detail. Analysis of the Aeos simulations has demonstrated that the initial steps of chemical evolution following the first Population III supernovae are highly non-monotonic. That is, halos do not see a steady increase in their overall metal content, rather, halos lose the majority of the chemical yield produced by Population III supernovae to the surrounding circumgalactic or intergalactic medium and remain essentially unenriched until they reach sufficient dark matter mass (~10^7 Msun) to retain reaccreted and injected gas and metals. I will discuss the impact this metal loss has on the onset of the formation of the first enriched stars, as well as implications for second-generation Population III stars. I will additionally explore how the recovery time between the last supernova explosion and subsequent star formation is influenced by galaxy properties and environment.

3D imaging spectroscopy and cosmological simulations to trace the chemical history of galaxies

Kathryn Grasha
Australian National University

Measuring the chemical history of galaxies is critical to understand how galaxies form and evolve. This is usually done through observations of emission lines from ionized nebulae, where their bright emission lines enable the measurement of physical properties, such as the gas-phase metallicity, across galaxy disks and in distant galaxies. In this talk I will present the newest state-of-the-art stellar evolution models based on the latest models of chemistry elements in the early universe to the determine chemical abundance patterns, pressure, star-formation rates, heavy element enrichment, and the production and escape of ionizing radiation from the first galaxies. Using these self-consistent chemistry and stellar population synthesis models, we use the observed stellar mass and detailed metallicity gradients to identify a best-fit to our galaxies within the IllustrisTNG cosmological simulations to characterize the likely chemical and accretion history. Our work suggests that the combination of cosmological simulations and high spatial resolution metallicity gradient observations can provide an archeological probe of the gas accretion and merger history of face-on spiral galaxies. With this, we are able to disentangle the different physical mechanisms regulate gas inflows and outflows and the resulting effects on the star formation activity. This project will exploit the next generation spectroscopy with the James Webb Space Telescope to make fundamental new measurements of the formation of stars in the first galaxies, linking the low and high redshift universes.

Nitrogen-enriched, Highly Pressurized Nebular Clouds Surrounding a Super Star Cluster at Cosmic Noon

Massimo Pascale
UC Berkeley

Strong lensing offers a precious opportunity for studying the formation and early evolution of super star clusters that are rare in our cosmic backyard. The Sunburst Arc, a gravitationally lensed Cosmic Noon galaxy, hosts a young super star cluster with escaping Lyman continuum radiation. I will present results from analyzing archival HST imaging and ground-based spectroscopy to construct a physical model for the cluster and its surrounding photoionized nebula. We confirm that the cluster is <4 Myr old, is extremely massive (M_star ~ 10^7 M_sun), and yet has a central component as compact as several parsecs. The cluster is surrounded by >10^5 M_sun of dense clouds which sit only 10 parsecs away from the stars, and have been pressurized to P~10^9 K/cm^3 by perhaps stellar radiation. The clouds are likely dusty as they show gas-phase depletion of silicon, and may be conducive to secondary star formation. Detection of strong rest-frame UV nitrogen emission lines implies heavy nitrogen enrichment, a factor of ~15 greater than typical local HII regions and comparable with stellar N abundances seen in the 2P stars of globular clusters. We suggest a physical origin of the high-pressure clouds from partial or complete condensation of slow massive star ejecta, which may have important implications for the puzzle of multiple stellar populations in globular clusters.

Unveiling Cosmic Dust Chronicles at early epochs with the James Webb Space Telescope

Ambra Nanni
National Centre for Nuclear Research

Cosmic dust is a cosmic storyteller which provides key information on the evolution of baryons in galaxies and their star formation histories (SFHs). The advent of the James Webb Space Telescope (JWST) marks a turning point to understand the role of these pivotal particles in the framework of galaxy evolution. With its unparalleled capabilities, JWST has recently revealed the presence of 2175 Å dust feature in galaxies up to z ~ 7 (JWST Advanced Deep Extragalactic Survey, JADES). Such a feature, well known up to redshift of 3, indicates the possible presence of carbonaceous grains at these early epochs. Furthermore, the large observed values of Halpha/Hbeta, indicative of large dust extinction, and strong oxygen lines, point at a fast enrichment of metals in their interstellar medium (ISM). In this talk, I will present our ongoing investigation aimed at constraining the metal build-up in JADES galaxies by modelling their spectra consistently with dust evolution in their ISM. Through such a study, it has been possible to shed light regarding the role of Type II Supernovae as metal and dust polluters, dust growth in the ISM, initial mass function of stars and SFH.

The impact of star formation and stellar feedback models on the properties of low mass galaxies

Anna Engelhardt
George Mason University

Ultra-faint dwarfs (UFDs) are hosted by the smallest dark matter halos discovered to date, and their small size makes UFD properties sensitive to prescriptions in subgrid physics models that converge at higher masses. The study of these low-mass systems has only recently been made possible through efforts to increase the resolution of modern hydrodynamical simulations. We compare two distinct SN feedback models: superbubble and blastwave in galaxies from the cosmological hydrodynamic zoom-in MARVELous dwarf and DC Justice League (DCJL) simulations. The MARVELous suite contains dwarf galaxies ranging in mass down to the UFD mass range and DCJL is a suite of Milky Way-like galaxies and their surrounding environments. We find that in the MARVELous simulations both feedback models produce cored galaxies and reproduce observed scaling relations for metallicity, luminosity, mass, and size. We also find that effective core formation peaks at 5x10e-3 M_star/M_vir for both feedback models. In the DCJL simulations we compare four different prescriptions for star formation. We find that different star formation recipes lead to diverging predictions for galaxy mean stellar metallicity and star formation histories. We show that, of our tested models, the model tied to the non-equilibrium abundance of H2 most accurately predicts the masses, metallicities, and metallicity dispersions of observed galaxies.

The Cool CGM of the Large Magellanic Cloud

Sapna Mishra
STScI

Only 50 kpc away, the Large Magellanic Cloud is the nearest massive galaxy to the Milky Way. This makes the LMC ideally suited for spatially resolving the CGM in UV absorption and probing the physics that governs the production of cool gas in galaxy halos. Existing data show the LMC CGM is complex and multi-phase, with recent work focusing on the existence of a hot (T~10^5.5 K) coronal phase. However, little is known about the origin and properties of diffuse cool (T~10^4 K) gas in the Magellanic CGM. Here, we characterize the diffuse cool CGM using UV low ions (O I, Si II, Si III, S II, Al II, Fe II, NiII) of the LMC in a sample of 28 AGN directions with publicly available HST/COS spectra. We find that the UV low ions around the LMC show a declining radial profile -- a column density that declines with impact parameter out to ~40 kpc - a characteristic signature of a diffuse multiphase CGM. In addition, unlike the other isolated low-z galaxies, the LMC CGM is truncated to one third of its viral radius, possibly due to its interaction with the MW and SMC. Next, using the analysis of these low ions together with ionization modeling and hydrodynamical simulations, we will form a comprehensive study of the size, mass, ionization, chemical enrichment, dust depletion, and survivability of the LMC's cool CGM. Altogether, this will allow us to quantitatively assess models of the origin and fate of the cool Magellanic CGM.

Hot Gas Properties of Local Starburst-Driven Outflows

Sebastian Lopez
The Ohio State University

Powered by parsec scale super-star clusters, local starburst galaxies M82, NGC 253, and NGC 4945, exhibit kiloparsec scale multiphase galactic outflows. These outflows, also known as galactic winds, can carry significant amounts of cooler gas and metals away from galactic disks and enrich the surrounding circumgalactic and intergalactic mediums. In this presentation using archival Chandra data, I will show the properties of hot galactic winds of nearby starbursts galaxies, such as their metal output, the geometry of the wind, and the properties of the cool clouds carried by them. We find that heavy elements are able to reach kiloparsec scales, though the distribution and level of metal enrichment between the galaxies differs. We find that starburst-driven outflows are best characterized by flared cylindrical geometry rather than the commonly assumed spherical geometry in wind models due to collimation from the disk. We also create a catalog of cool clouds in M82's hot wind and find their properties are in general agreement with recent theoretical work on cloud survival.

Joint ALMA+JWST analysis of the circumgalactic medium of MACS1931-26

Laya Ghodsi
The University of British Columbia

The evolution of galaxies is affected by the diffuse gas around them known as the circumgalactic medium (CGM) through gas inflows and outflows. In this work, we report an investigation of the CGM and ISM of the brightest central galaxy (BCG) of a galaxy cluster, MACS1931-26 at z~0.35 with one of the largest known H2 reservoirs, elevated star formation, and strong radio AGN. We have detected cold H2 towards MACS1931-26 using the [CI](2-1), CO(1-0) and CO(7-6) lines with the APEX 12-m and NRO 45-m telescopes. We complement these observations with archival ALMA CO data and model the gas and dust physical properties using a modified large velocity gradient (LVG) model. Our study shows that the gas in the BCG is highly excited, comparable to the local ULIRGs. However, the CGM gas is less excited, colder, less dense, and less virialized. The H2 mass of the whole system derived using [CI](2-1) is larger than the H2 mass derived using CO(1-0), showing that a part of the gas in this system is CO-poor. Our recent observations of this object using JWST reveal warm H2 concomitant with the cold H2 detected by ALMA. A joint analysis of the cold and warm H2 with these two data sets would reveal any potential gas flow from the CGM to the BCG of this system which might fuel the enhanced star formation of this galaxy and correlate with the strong radio AGN in this system.

Spatial distributions and kinematics of z~0.35 star-forming and confirmed LyC (non-) leakers

Floriane Leclercq
UT Austin

The geometry and flows of gas in and around galaxies are key regulators of star formation and underlying production and escape of ionizing photons. I will present the first statistical study (Leclercq et al. tbs) aiming at characterizing the neutral and ionized gas distributions and kinematics of 22 star-forming galaxies at z~0.35, comprising both LyC leakers and non-leakers that resemble epoch of reionization (EoR) galaxies (see LzLCS survey, Flury et al. 2022). Using the Keck/KCWI and HET/LRS2, we detected neutral gas (using MgII) and ionized gas (using [O II]) extending with the circumgalactic medium (CGM, i.e., beyond the continuum) for 7 and 10 objects, respectively. While strong LyC leakers (escape fraction fesc>10%) appear uniformly compact in both MgII and [O II] (<1kpc), non/weak leakers (fesc<5%) show diverse gas configurations. We also measure spatial offsets between the nebular gas and the stellar continuum emission, which could be due to star-forming sub-structures, scattering effects in the CGM or faint satellites. We find significant anti-correlations between the neutral gas extent and the O32 ratio, Hβ EW and UV size, as well as a positive correlation with metallicity, suggesting that highly ionized galaxies have compact neutral gas sizes. We find no correlation with M* or SFR. Our [O II] and MgII spatially resolved maps reveal dispersion-dominated rotation and spatial variations in the HI column density, respectively. MgII maps are redshifted compared to [O II], indicating outflowing gas for most of our local analogues of EoR galaxies.

Enrichment of the multi-phase circumgalactic medium in dwarf galaxies from CUBS and MUSEQuBES

Sean Johnson
University of Michigan

The circumgalactic medium represents the principal reservoir for fueling star formation in galaxies over long timescales. At the same time, its chemical enrichment and physical conditions contain a record of past outflows and feedback, making the CGM an ideal laboratory for improving our understanding of the cosmic ecosystems that govern galaxy evolution. The metallicities, extent, and physical conditions of the CGM around star-forming field dwarf galaxies are particularly sensitive to feedback physics due to their shallow gravitational potential wells and isolated nature. I will present results from recent surveys combining sensitive HST absorption spectroscopy of the CGM around dwarf galaxies uncovered by the CUBS and MUSEQuBES surveys, which combine deep integral field spectroscopy to discover faint galaxies and wide-field redshift surveys to characterize their environments. These surveys increase the number of dwarf galaxies with absorption measurements of multi-phase metal lines, including low (e.g., CII, SiII), intermediate (e.g., CIII, SiIII, SiIV), and high (OVI) ions by a factor of ten, significantly advancing our empirical knowledge of the baryon cycle around low mass galaxies. Furthermore, the intermediate redshifts (z~0.3) of the galaxies enable accurate HI column density measurements, providing the first measurements of the metallicities of the cool, ionized phase of the CGM of dwarf galaxies with ongoing star formation for new insights into stellar feedback and the metal budget.

The stellar populations of gas-rich absorbing galaxies: the essential link to the baryon cycle

Ramona Augustin
Leibniz-Institut fuer Astrophysik Potsdam (AIP)

Studying the processes of how gas gets accreted onto galaxies, forms stars, and is then expelled from galaxies is crucial for understanding galaxy evolution. While observing all these components in the same system is challenging, cosmological hydrodynamical simulations indicate that the stellar mass of galaxies is a key factor that significantly influences circumgalactic medium (CGM) properties. We test this prediction by characterizing the cold gas in the CGM of a sample of z∼1 galaxies using absorption lines from the spectrum of background quasars. The MUSE-ALMA Haloes survey, covering quasar fields with both VLT/MUSE and ALMA observations, reveals 32 strong HI absorbers associated with 79 galaxies at $0.2 < z < 1.4$. I will present results from the analysis of a 40-orbit medium campaign using HST UVIS and IR WFC3 imaging to determine the stellar content of these galaxies. We find that these objects show a wide range of stellar masses ($8.1 < \log(M^*/M_{sol}) < 12.4$) with star-formation rates following the main sequence. We confirm and for the first time quantify an anti-correlation between stellar masses and CGM atomic hydrogen column density N(HI), indicating an evolutionary trend where higher mass galaxies are less likely to host significant HI gas reservoir in their immediate vicinity up to 120 kpc. All together, the MUSE-ALMA Haloes survey performs complete census of the condensed baryons in these galaxies, characterizes their dynamical structure and quantifies the CGM metal enrichment as a function of stellar mass

Galaxy local environments and star formation burstiness in low-mass high-z galaxies

Yoshihisa Asada
Kyoto University

Early results from JWST observations have suggested that star formations in high-z galaxies are highly bursty – fluctuating with very short timescales – but the cause of such bursty star formations is still under debate. We will present our results investigating the star formation burstiness and the local environments of low-mass galaxies at z∼5-6. We used five different line-of-sight JWST observations of gravitational lensing cluster fields by the CAnadian NIRISS Unbiased Cluster Survey (CANUCS), to explore low-mass galaxies at high-z in various environments. We found that the galaxy-galaxy interaction seems to be a quite common phenomenon among high-z low-mass galaxies, and the clustered environments or galaxy-galaxy interactions indeed enhance the star formation burstiness in low-mass high-z galaxies, by enabling rapid bursts of star formation and subsequent fast quenchings. Our results suggest the galaxy local environment is quite pivotal in early-phase galaxy assembly. In the talk we also show results from NIRSpec follow-up observations to further discuss the physical origins triggering bursty star formations in low-mass interacting galaxies at high-z.

The evolution of intervening metal absorbers at 2<z<7 using E-XQR-30

Alma Sebastian
Swinburne University of Technology, Hawthorn

Metals play an important role in star formation activity in galaxies across different epochs. These heavy elements produced through stellar nucleosynthesis processes are expelled from the galaxies to the surrounding circumgalactic (CGM) and intergalactic media (IGM) through various feedback mechanisms such as galactic winds and supernovae. Obtaining a census of metals in the CGM across cosmic time thereby provides an independent measure of the global stellar production and galactic baryon cycle in different epochs. Here, I present my results on the comoving line density (dn/dX) of intervening absorbers such as Mg II, C II and O I across redshift ranging from z∼2 to 6 using the E-XQR-30 (The Extended Ultimate XSHOOTER Legacy Survey of Quasars at z∼5.8-6.6) metal absorber catalog prepared using high quality spectra from 42 bright quasars using an ESO-VLT Large Program. The improved resolution and sensitivity of E-XQR-30 have enabled us to calculate the first ever number density statistics of a large population of 131 weak intervening Mg II (with an equivalent width of W<0.3Å) systems at z>2. Overall, our results indicate that there has been significant enrichment of the CGM mostly through core-collapse supernovae from the tail end of the Epoch of Reionization (EoR) to the cosmic noon era.

Bridging Observations and Simulations of the Resolved CGM with the Dragonfly Spectral Line Mapper

Imad Pasha
Yale University

The multiphase circumgalactic medium is a critical component of galactic environments and evolution, but to date, few observations have successfully produced spatially resolved maps of CGM gas around individual systems. It is similarly challenging to simulate, with large volumes, low densities, and multiscale physics at play driving the ultimate heating, cooling, and emission processes. The next evolution of CGM studies involves progress in both of these regimes, with CGM focused, high resolution simulations complementing observed emission maps in, e.g., H-alpha, [NII], and [OIII] measured by new instruments and facilities (e.g., Keck/KCRM, VLT/MUSE, Dragonfly Spectral Line Mapper (DSLM), CHaS). Connecting mocks from new simulations with these maps will be a vital step in constraining physical models of the CGM. Here, we present initial maps inferred from the TNG50 and FIRE-2 simulations, with a focus on creating mocks matched to the observing conditions of the DSLM. We assess the kinds of observing strategies required with the instrument to detect relevant gas features, e.g., filamentary accretion, clumps or clouds at kpc scales, and outflows. We compare these simulated maps to preliminary results from DSLM for a pilot set of galaxies. We then discuss in-progress and upcoming simulations which would be well-suited to the creation of constraining maps for comparison with forthcoming data, which better resolve CGM processes and the emission produced via, e.g., radiative transfer.

CIRCUMGALACTIC MEDIUM AT HIGH REDSHIFTS: CONNECTING COSMOLOGICAL FILAMENTS WITH CENTRAL GALAXIES

Da Bi
University of Concepcion, Chile

We use high-resolution zoom-in cosmological simulations to study the evolution of circumgalactic medium (CGM) at high redshifts. Filamentary and diffuse accretion in conjunction with stellar and galactic outflows have been analyzed for central galaxies in the similar mass DM halos, log M/Mo ~10.75, at the final z=6, 4, and 2. Two feedback mechanisms, steady and variable winds, have been implemented in high and low-density environments. We focused on the evolution of baryonic filamentary and diffuse accretion processes within few virial radii. Specifically, we have addressed the developing turbulence and ablation of penetrating streamers, and their interactions with the galactic outflows, thus determinig the kinematic and thermodynamic properties of the CGM between the central galaxy and the backsplah radii. In addition, we have post-processed our galaxy sample with a radiative transfer scheme to obtain their observational properties, for the future observations with the JWST.

Arkenstone: Simulating CGM-based Star Formation Regulation with High Specific Energy Outflows

Greg Bryan
Columbia University

There is emerging theoretical and observational evidence that star-forming galaxies drive high-specific energy outflows rather than highly mass-loaded winds. These outflows can heat gas in the circumgalactic medium (CGM) and beyond, lifting the gas to higher adiabats and radii, preventing later accretion. This provides a mechanism to regulate star formation in galaxies at the CGM level rather than purely at the galactic level. This is done through preventive feedback, with supernovae or active galactic nuclei heating the CGM to regulate inflow driven by radiative cooling rather than ejective feedback. I will present recent work unveiling a new numerical methodology ("Arkenstone") that allows high-specific energy flows and cold, dense clouds to be accurately modeled in cosmological simulations even at the relatively low resolution required in cosmological simulations. The hot and cold outflows are evolved independently but self-consistently using subgrid models derived from high-resolution simulations of the turbulent radiative mixing layers that form at hot-cold interfaces.

Expandable Galactic Atmospheres and the Physics of Galaxy Self-Regulation

Viraj Pandya
Columbia University

I will present a fundamentally new model of star formation regulation in galaxies that is directly coupled to the evolution of their galactic atmospheres. In this model, the energy carried by supernovae and active galactic nuclei (AGN) can heat and drive turbulence in the circumgalactic medium (CGM), in turn suppressing gas accretion and hence star formation in galaxies. I will show that these effects can cause galactic atmospheres to expand leading to reduced halo baryon fractions as inferred for dwarfs. I will also describe how we are leveraging this novel CGM--galaxy co-evolution framework to constrain star formation, quenching and stripping processes in satellites around Milky Way analogs. Finally, I will introduce the first "automatically differentiable" Bayesian model of this type and demonstrate how it enables fast and robust parameter inference using observations of both galaxies and their atmospheres at a variety of redshifts.

Regulating Star Formation with a Hot Circumgalactic Medium

Chris Carr
Columbia University

Galactic models have typically assumed that supernova-driven outflows regulate star formation in low-mass galaxies through ejecting a large fraction of the gas which enters the disc, even though such highly mass-loaded winds are at increasing tension with observations and high-resolution simulations of supernova winds in the multiphase interstellar medium (ISM). In this talk, I will introduce our simple gas-regulator model to study the key processes governing star formation in galaxies, where the ISM, the stellar mass, and the circumgalactic medium (CGM) are modeled as distinct reservoirs which exchanges mass, energy, and metals at different rates within a growing halo. With an emphasis on the stellar-to-halo mass relation and the metallicity content of low-mass galaxies, I will show that the primary role of SNe-driven outflows in regulating star formation is not by ejecting highly mass-loaded winds as the traditional ejective feedback models have assumed, but by launching hot, energy-loaded outflows that heat and expand the surrounding CGM and limit its cooling efficiency. This form of preventive feedback constrains the accretion of gas to the ISM and in turn, regulates star formation in the galaxy. Lastly, I will present preliminary results from our latest extension of the model to demonstrate that the relative abundances of metals produced from different nucleosynthetic sources, such as from core-collapse supernovae or asymptotic giant branch stars, in the ISM and CGM could be a key observable diagnostic for the relative importance of ejective and preventive feedback in galaxies.

Growing Pains: Disruption from Superbubble Feedback Across z ~ 3-0 in Simulated Galaxies

Lori Porter
Columbia University

We present an investigation of clustered stellar feedback in the form of superbubbles identified within eleven galaxies from the FIRE-2 (Feedback in Realistic Environments) cosmological zoom-in simulation suite, at both cosmic noon (3<z<1) and in the local Universe and investigate the spatially-resolved multiphase outflows that these supernovae-driven winds drive, comparing our findings with recent theory and observations. These simulations consist of five dwarf galaxies and six Milky Way-mass progenitors (with a minimum particle mass of 7100 M_{\odot}), for which we calculate the local mass and energy loading factors from the identified outflows. We also characterize the multiphase morphology and properties of the identified superbubbles, including the 'shell' of cool gas and outbreak of energetic hot (T>10^5 K) gas. For all galaxies, mass, momentum, and energy fluxes appear to reach their peak during the identified superbubbles, and we investigate this influence on the interstellar medium (ISM), circumgalactic medium (CGM), and subsequent star formation rates. We find that these simulations, regardless of redshift, have mass-loading factors and momentum fluxes in the cool (T<10^5 K) gas that largely agree with recent observations and characterize the morphology and phenomenology of the stellar feedback occurring. We also further investigate how different scales of outflows and momentum implementation in FIRE may affect measurements of supernovae-driven galactic winds.

The timescales and drivers of Milky Way satellite quenching

Charlotte Christensen
Grinnell College

The small potentials of dwarf galaxies make them uniquely sensitive environments for understanding the physics of galaxy-wide star formation, including the processes that drive gas accretion and gas loss. Dwarf satellites of the Milky Way or similar nearby galaxies can act as laboratories for understanding the role of environment in quenching star formation. Here, I use a suite of high-resolution cosmological simulations of Milky Way-mass galaxies to examine how the halo environment affects satellite star formation by modifying the rates of gas accretion and expulsion. By using particle tracking, we determine the characteristics and rates of gas loss. I show evidence for the importance of ram pressure in driving gas loss, and I demonstrate how both the initial gas content and the trajectory of the satellite in combination with ram pressure determines the timescales over which star formation is quenched. I further show how stellar feedback can assist in gas loss, especially in the most massive satellites.

Uncovering Massive Reddened Quasars in the Early Universe

Vasily Kokorev
Kapteyn Astronomical Institute

Deep observations with JWST have revealed an emerging population of red point-like sources that could provide a link between the postulated supermassive black hole seeds and observed quasars. In this talk I present a JWST/NIRSpec spectrum from the JWST Cycle 1 UNCOVER Treasury survey, of a massive accreting black hole at z = 8.50, displaying a clear broad-line component as inferred from the Hβ line. Combining the derived black hole mass with the detailed modeling of the spectral energy distribution in the optical and near-infrared, together with constraints from ALMA we find an unprecedented ratio of black hole to host mass of at least ∼ 30%. This is orders of magnitude higher compared to the local QSOs, but is consistent with recent AGN studies at high redshift with JWST. In conjunction with other literature works on high-z quasars this finding suggests that a non-negligible fraction of supermassive black holes either started out from massive seeds and/or grew at a super-Eddington rate at high redshift. It is clear that these objects play an important roles in the story of black hole growth at early times, however so far a systematic review of these enigmatic AGN across multiple fields has not been undertaken. To this end, I will present my most recent work which explores deep JWST photometry in blank fields, covering ∼0.1 deg^2, to select and study a statistical sample of these enigmatic red compact objects.

Extended Dusty Star Formation Halfway Back to Cosmic Noon

Jason Young
University of Massachusetts Amherst

What physical processes drove the slowdown in star formation from cosmic noon to today? We present results from the JWST cycle 1 program "Halfway to the Peak", which explores star formation in seven luminous infrared galaxies at z~0.6, halfway between cosmic noon and today. Our MIRI/MRS IFU data show extended atomic, molecular, and PAH emission features, indicating extended current/recent star formation. We will examine PAH and atomic lines ratios sensitive to ionization as a function of AGN fraction, which will help discern the role of feedback in regulating star formation during this transitional era. Since our objects are spatially resolved, these data allow use to examine the uniformity of emission features across the disks of this sample, which will discern between rapid or gradual evolution of star formation in these objects.

Insights into z>6 SFHs and early cosmic chemical evolution from z>3 massive quiescent galaxies

Themiya Nanayakkara
Swinburne University of Technology

With JWST/NIRSpec observations we are now able to perform detailed spectroscopic measurements of rest-frame optical features of z>3 massive quiescent galaxies. By analysing the links between Balmer absorption lines with alpha element sensitive features and comprehensive spectra + photometry (SED) fitting techniques we are able to provide tight constraints to the formation histories of these sources. Even with R~100-500 lower-R spectroscopy we are able to identify galaxies that formed ~10**11 msol within the first 500 million years (by z~10) of the Universe. The strong alpha element spectral signatures along with features that are commonly observed in AGB star dominated z~0 massive quiescent galaxies provide us an opportunity to study the detailed chemistry of these z~3 massive quiescent systems. In my talk I will discuss the formation history of z>3 massive and quiescent galaxies, the role of AGN in forming these systems, and discuss implications this buildup of stellar mass which may have for z>6 star-formation efficiencies and hierarchical galaxy growth scenarios.

The impacts of AGN feedback in a local galaxy: the case of NGC7469 from the eyes of JWST-NIRSpec

Marina Bianchin
University of California, Irvine

We study gas kinematics and excitation of the luminous infrared galaxy NGC 7469: a nearby (70.6 Mpc) active galaxy with a Sy 1.5 nucleus that drives a highly ionized gas outflow and a prominent nuclear star-forming ring. We use the ERS observations carried out with the NIRSpec instrument in the IFS mode. The observations cover 1.4x1.6 kpc2 corresponding to the nuclear and ring region. We investigate the gas excitation through H2/Brɣ and [FeII]/Paβ emission line ratios and find that photoionization by the AGN dominates within the central 300 pc of the galaxy except in a small region that shows signatures of shock-heated gas; these shock-heated regions are likely associated with a compact radio jet. In addition, the velocity field and velocity dispersion maps reveal complex gas kinematics. Rotation is the dominant feature, but we also identify non-circular motions consistent with gas inflows as traced by the velocity residuals and the spiral pattern in the Paα velocity dispersion map which are two orders of magnitude higher than the AGN accretion rate. The Paα line profile also reveals the presence of a broad component, besides the BLR component, that we associate with a turbulent outflow. The compact radio jet in NGC 7469 has enough power to perturb the gas and create the turbulence observed in the outflow, which may prevent star formation in the inner region of the galaxy.

NIRCam Observations of NGC 4258 - A Nearby Galaxy to Study Star Formation History on Multiple Scales

Isha Nayak
NASA Goddard Space Flight Center

We present high-resolution JWST Near-Infrared Camera (NIRCam) imaging of NGC 4258, a galaxy located 7.2 Mpc away, offering an excellent opportunity to explore the impact of AGN feedback on star formation regulation and gas expulsion (i.e. negative feedback). Observations include [Fe II], Paschen-alpha, molecular hydrogen, PAH emission, Brackett-alpha, and several continuum band distributions, which we utilize to A) investigate the influence of shocks in both the star-forming spiral arm and anomalous spiral arm on current and past star formation within NGC 4258 and B) analyze color-magnitude diagrams (CMDs) to reveal diverse stellar populations within NGC 4258, including young stellar objects, asymptotic giant branch stars, red giant branch stars, red clump stars, and a possible detection of supergiant stars. We identify a correlation between the previously observed anomalous spiral arms in NGC 4258 from radio observations and NIRCam observations of [Fe II] and molecular hydrogen, which suggests that the radio emission is likely a result of shocks. Our modeling of young stellar object photometry indicates these young protostars have masses ranging from 10 to 30 Msun. Given the 7.2 Mpc distance, it is likely that we are observing stellar clusters with masses in the same range. We investigate these young stellar objects and older asymptotic giant branch stars on both parsec and galactic scales to gain insights into the processes driving star formation, such as galactic mergers, AGN feedback, and the influence of winds and jets from massive O stars.

The molecular view of AGN feedback at cosmic noon: do AGN gas-deplete their hosts?

Elena Bertola
INAF - Observatory of Arcetri

Active galactic nuclei (AGN) are thought to play a key role in shaping the buildup of galaxies. If AGN influence galaxy growth, then they will reasonably impact the molecular gas reservoir first, and star formation (SF) as a consequence. Literature results concerning the gas content of high-z AGN hosts often focused on high-luminosity AGN (log(LBol/erg/s) > 46), i.e. good candidates for driving outflows. The SUPER and KASHz surveys are complementary projects that aim at assessing AGN feedback in samples of unbiased, X-ray-selected AGN at cosmic noon. The SUPER project recently found that significant CO depletion is present only in the

most massive host galaxies (log(M*/Msun) > 11), demonstrating the importance of using unbiased samples representative of the AGN population at cosmic noon.
I will present our comparative study of the total molecular gas content, as traced by CO, of a sizable sample of cosmic noon AGN, obtained by merging SUPER, KASHz and carefully-selected literature AGN available in the ALMA archive, and a control sample of matched non-AGN galaxies. Applying the Bayesian framework developed by the SUPER project, the trends shown by AGN and non-AGN galaxies at cosmic noon are statistically consistent. Yet, AGN and non-AGN show a significantly different gas fraction distribution, with AGN shifted and skewed to lower values, consistent with negative AGN feedback effects. Lastly, I will report on the comparison between our observational results and the predictions of cosmological simulations.

"MIRI-MRS Insights: Unraveling the Kinematics of LIRGs at z~0.6"

Miriam Eleazer
University of Massachusetts, Amherst

We present the kinematics of seven Luminous Infrared Galaxies (LIRGs) using MIRI-MRS data taken as part of a Cycle 1 program. These galaxies are observed at $z\sim0.6$, halfway back to the peak epoch of cosmic star formation when galaxies were actively evolving and span a range of AGN fractions allowing us to explore how the powering mechanism might influence the kinematic signatures observed in spectral lines. We explore the atomic spectral line profiles to search for indicators of rotation, interactions, and outflows. Leveraging the exceptional spatial resolution of MIRI-MRS data, we isolate the nuclear regions of these galaxies for comparison with their circumnuclear regions. Lastly, we calculate velocity and dispersion maps for the [ArII], [NeII], and H2S(5) spectral lines which allows us to measure the distribution and motion of different gas components within these galaxies. This study explores the impact of AGN on kinematics, providing valuable information on AGN feedback's role in star formation regulation contributing valuable insights into the complex interplay between star formation, AGN activity, and cosmic environments.

The Role of AGN Feedback in the CAMELS Simulations in Regulating SFR and SMBH Seeding

Megan Tillman
Rutgers University

The low redshift Lyman-α (Lyα) forest ($z \lesssim 2$) presents a challenge for both observers and theorists. Observationally, it is difficult to collect data due to the need for high resolution space-based FUV spectrographs. The observational data we do have for the forest (which lies largely below z=0.5) challenges predictions from cosmological hydrodynamic simulations. In order to resolve theory and observation in this context, a better understanding of the mechanisms that alter the thermal state of the intergalactic medium is necessary. In particular, galactic feedback mechanisms are likely to play a role in resolving the theorized and observed low-z Lyα forest, especially that from active galactic nuclei (AGN), a feedback mechanism that is still largely unconstrained. Using the Cosmology and Astrophysics with Machine Learning Simulations (CAMELS) suite, we explore variations of the AGN and stellar feedback models in the IllustrisTNG and Simba sub-grid models and their effects on the low-z Lyα forest. Through our studies of the low-z Lyα forest, we find that stellar feedback plays a prominent role in regulating supermassive black hole growth and feedback. These results highlight the importance of constraining stellar and AGN feedback models simultaneously.

Modelling the impact of AGN-driven winds on galaxy sizes

Rachel Cochrane
Columbia University

I will present work quantifying the impact of AGN-driven winds on the intrinsic (particle-based) and observable (light-based, in different wavebands) sizes of simulated galaxies. This study makes use of the FIRE simulations, with a state-of-the-art hyper-Lagrangian refinement technique to increase particle resolution and hence resolve the wind. Mechanical winds suppress a very compact starburst event observed in the no-feedback simulation and maintain a half-mass radius that is approximately constant with time. We run radiative transfer calculations to study the observable impact of AGN feedback on multi-wavelength continuum emission and find notable differences between the simulations with and without winds, in both the magnitude and spatial extent of observable short and long-wavelength flux. When AGN winds are included, the suppression of the compact, dusty starburst results in lowered flux at FIR wavelengths (due to decreased star formation) but increased flux at optical-to-near-IR wavelengths (due to decreased dust attenuation, in spite of the lowered star formation rate), relative to the case without winds. The FIR half-light radius decreases from $\sim$ 1 kpc to $\sim$ 0.1 kpc in < 40 Myr when AGN winds are not included, but increases to $\sim$ 2 kpc when they are. The impact of AGN-driven winds at shorter wavelengths is less intuitive, with half-light radii of optical-NIR emission remaining approximately constant over t = 35 Myr, for simulations with and without AGN winds. In the case without winds, this occurs despite the rapid compaction, and is due to heavy dust obscuration in the inner regions of the galaxy. This work highlights the importance of forward-modelling when comparing simulated and observed galaxy populations.

The z=0 Distribution of Star Formation in TNG100 Galaxies: Intrinsic and Environmental Factors

Bryanne McDonough
Boston University

Several processes have been implicated as driving or influencing quenching of star formation in galaxies, including AGN feedback, a bar morphology, and environment. In this talk, I will use radial profiles of stellar age and star formation rate for populations of galaxies in the TNG100 simulation to explore how and where these factors influence star formation. I demonstrate that high-mass TNG100 galaxies reproduce the observed inside-out quenching driven by AGN feedback energy and will show that the gradient in stellar age is directly related to the cumulative AGN energy injected. I will also summarize results from an ongoing study of the effects on similar profiles for low-mass and satellite galaxies in TNG100 with the goal of demonstrating how morphology and environment affect star formation in these populations.

Galaxy Quenching at the High Redshift Frontier with JWST

Asa Bluck
Florida International University

In the local Universe there is distinct bimodality observed in galaxy properties, such that most local systems are either actively star forming or non-star forming ('quenched'). Quenched galaxies are observed up to the first Gyr in the Universe's history in unprecedented JWST observations. In this talk we identify the key testable predictions from AGN feedback driven quenching from contemporary cosmological models (e.g., EAGLE & IllustrisTNG). We then test these predictions across cosmic time with the SDSS (at $z \sim 0$), HST-CANDELS (at $z \sim 0.5 – 2$), and JWST-CEERS (at $z \sim 2 – 8$). Simulations predict that AGN feedback driven quenching will ultimately depend on the supermassive black hole (SMBH) mass, with little dependence on accretion rate or AGN luminosity. This has profound implications for the empirical study of quenching at all epochs. In lieu of dynamical measurements of SMBH masses for large statistical samples, the models predict that the galaxy stellar potential should appear as the key driver of quiescence in machine learning classification analyses, which carefully remove spurious inter-correlations between galaxy properties. This prediction is met precisely across 13 Gyrs of cosmic history (from $z = 0 – 8$). Hence, we conclude that AGN feedback has likely been quenching star formation in massive galaxies since the first Gyr of the Universe's history.

Quenching via Tidal Removal of Cold Gas from Intermediate-redshift Massive Post-starburst Galaxies

Vincenzo D'Onofrio
Texas A&M University

Theoretical models and observations have shown that star formation requires active suppression to prevent the formation of overly massive galaxies. We understand that most massive ellipticals rapidly stopped forming stars, but the dominant physical process responsible is debated. While mechanisms including SMBH accretion and feedback driven outflows are often proposed to regulate the cold molecular gas reservoirs available, they may not be the only pertinent quenching processes. We present the discovery of vast cold gas (ALMA CO) tidal features in two massive $z{\sim}0.7$ post-starburst galaxies that recently halted their primary period of star formation. Extending up to 65 kpc outside of the galaxies, the molecular tidal features contain approximately half of the total cold gas available in their respective systems. The tidal features are unmatched compared to all known merging galaxies at any redshift in terms of extent and magnitude. We infer that the merger is responsible for causing the initial burst and subsequent quenching of star formation in both galaxies, stripping cold gas from the host systems. As part of a multiwavelength campaign, HST observations exhibit stellar tidal features in both objects. Only in the lower-redshift object are extended CO features aligned with the stellar tails which host regions of H-alpha emission suggesting moderate ongoing star formation, perhaps displaced during the merger. VLA 6GHz data show evidence for central AGN, albeit weak in the higher-redshift counterpart. The incongruity of these systems beyond the extended CO features suggest that different processes are maintaining quenching.

AGN Feedback in Quiescent Galaxies at Cosmic Noon Traced by Ionized Gas Emission

Letizia Bugiani
Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy

The quenching of star formation in massive galaxies is commonly attributed to AGN feedback, either through effective removal of gas from the system or through continuous gas heating: yet, direct observational evidence of these mechanisms at work has remained elusive, especially at high redshift. We analyze ionized gas emission lines in deep rest-frame optical spectra of 22 quiescent galaxies at $1.7 < z < 3.5$ observed by JWST NIRSpec in the COSMOS field, to investigate the quenching mechanism at work.
Solid detection of emission lines in 82% of the spectra indicate ongoing ionizing sources in this passive population. No X-ray or radio detection for these galaxies was found; however, 8 galaxies in the sample are classified as AGN hosts by their emission line ratios, including one broad-line AGN. Additionally, 4 AGN-hosting galaxies exhibit powerful ionized gas outflows with typical velocities of ~ 1000 km/s, likely due to AGN feedback. One galaxy at z=2.445 also shows a massive neutral gas outflow traced by resonant absorption lines: its total mass outflow rate is larger than the residual star formation rate, implicating rapid star-formation quenching through gas ejection. The general picture emerging from this study is that massive quiescent galaxies at Cosmic Noon harbour a significant fraction of never-before-detected AGN. Furthermore, detections of gas outflows are consistent with a direct link between quenching of star-formation in massive quiescent galaxies and AGN feedback via high-velocity gas ejection.

Posters

Dust around massive stars is agnostic to galactic environment: New insights from PHAT & BEAST

Christina Lindberg
Johns Hopkins University

Resolving the environments of massive stars is crucial for understanding their formation mechanisms as well as their impact on galaxy evolution. An important open question is whether massive stars found in diffuse regions outside of spiral arms formed in-situ or migrated there after forming in denser environments. To address this question, we use multi-resolution measurements of extinction in the Andromeda Galaxy (M31) to probe the interstellar medium (ISM) surrounding massive stars across a variety of galactic environments.

We construct a catalog of 42,107 massive star candidates using resolved stellar photometry from the Panchromatic Hubble Andromeda Treasury (PHAT) program plus stellar and dust model estimates by the Bayesian Extinction and Stellar Tool (BEAST). We quantify galactic environments by computing surrounding stellar densities using kernel density estimation. We then compare high-resolution line-of-sight extinction estimates from the BEAST with 25-pc resolution dust maps from PHAT which measure the total column density distribution of dust.

Our key finding is that, although the average total column density of dust increases with the density of stars, the average line-of-sight extinction towards massive stars remains constant across all environments. This suggests that massive stars have a uniform amount of dust in their immediate environment, regardless of their location in the galaxy. One possible explanation for these findings is that small molecular clouds are still capable of forming massive stars, even if they are not resolvable at 25-pc. These results indicate that massive stars are forming in the sparse regions of M31, as opposed to migrating there.

Properties of Giant Star-forming Clumps and their Host Galaxies Observed by HST and JWST

Alec Martin
University of Missouri - Columbia

Giant star-forming clumps are a prominent feature of star-forming galaxies (SFGs) and contain important clues on galaxy formation and evolution. We used the HST/WFC3 F275W images from the Ultraviolet Imaging of the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (UVCANDELS) to investigate the basic demographics of clumps and clumpy galaxies at redshift $0.5 < z < 1$, connecting two epochs when clumps are common (at the cosmic high-noon, $z{\sim}2$) and rare (in the local universe). We found that clumpy galaxies are on average larger in size, higher in SFR and bluer in color compared to non-clumpy SFGs of the same mass. They are, however, similar in overall morphology to non-clumpy SFGs as indicated by their Sérsic index. We also found that on average, more luminous star-forming regions reside in more luminous, smaller, and/or higher-specific SFR galaxies and are found closer to their hosts' galactic center. Our results are consistent with in-situ clump formation through violent disk instability. We combined HST images with JWST CEERS images to measure the physical properties of clumps (M*, SFR, age, and Av) at $0.5 < z < 3$. We find that the addition of JWST observations significantly improves the precision of our clump physical property estimates for high redshift clumps within our sample, while the results for the lower redshift clumps indicate the need for further observations in the UV. These properties will further be compared to the state-of-the-art simulations to constrain the effects of feedback on clump evolution.

PHANGS-HST catalogs for ~100,000 star clusters and compact associations in 38 galaxies

Daniel Maschmann
Steward Observatory

We present the largest publicly available catalog of star clusters and compact associations, containing ~100,000 objects identified in 38 nearby galaxies (4 - 23 Mpc). The catalog is based on the PHANGS-HST Treasury Survey, which has obtained NUV, U, B, V and I imaging and is available on MAST. We show that to correctly characterize the evolutionary stage of star clusters the NUV and U band in addition to the conventional BVI bands are necessary. The UBVI color-color diagram of all objects aggregated across the 38 galaxies reveal three characteristic demographic regions: the young cluster locus, the middle-age plume, and the old globular cluster clump. Via spatial distribution analysis we see how young star clusters, formed in dense, molecular gas rich regions, free themselves from their dusty nursery and become progressively more dispersed over their lifetime, eventually reaching an almost uniform distribution, as seen for old globular clusters. We find that the relative cluster demographics of a galaxy are an excellent surrogate of its evolutionary stage: The fraction of young and middle aged clusters correlates with the galaxy's position relative to the main sequence of star forming galaxies. All in all, the new PHANGS-HST cluster catalog not only brings a growth of a factor ~10 in statistics compared to literature samples but also provides additional coverage at different wavelengths with ALMA, VLT-MUSE and JWST observations. The presented sample is an outstanding resource for testing our understanding of star formation in the context of galaxy evolution.

The Paschen-alpha Star Forming Sequence at z~1-2

Chloe Neufeld
Yale University

The star forming sequence of galaxies - the tight relation between star formation rate (SFR) and stellar mass - is an informative probe of galaxy evolution, with implications for how galaxies build up their mass and eventually quench. Long wavelength hydrogen recombination lines in the rest-frame near infrared (NIR), such as Paschen-alpha, are nearly dust-insensitive tracers of SFR that can now, for the first time with JWST, be explored at cosmic noon. I will present results from the FRESCO survey on the star forming sequence of galaxies at z~1-2, near the peak of cosmic star formation rate density, measuring SFRs from the redshifted Paschen-alpha emission line. Using these clean, model-independent measures, I will show comparisons with previous studies using a variety of SFR probes, including sophisticated SED fitting frameworks. I will also investigate the information contained in the emission line maps produced by grism spectroscopy. These line maps allow us to see where Paschen-alpha emission - and thus star formation - is present in these galaxies, allowing for spatially resolved investigations into galaxy quenching and dust obscured star formation.

Far-infrared spectral lines as tracers of the impact of stellar feedback

Jorge Pineda
Jet Propulsion Laboratory

Far-infrared (FIR) fine structure lines, such as [CII], [NII], [OI], and [OIII], are powerful tools for understanding the evolution of the interstellar medium (ISM) and star formation in galaxies. In particular, these spectral lines are important tracers of the radiative and mechanical energy input that stellar feedback injects into the interstellar medium. In this talk I will review recent results in the Milky Way using far infrared spectral lines to measure the kinetic energy and momentum injected by stellar feedback into the interstellar medium. Such observations have the potential to enable the determination of the stellar feedback energy and momentum loading factors in galaxies, which are fundamental but poorly constrained parameters in numerical models of galaxy evolution. I will also discuss measurements of the distribution of metal abundances derived from FIR lines in the inner Milky Way which complement our understanding of the chemical evolution of galaxies derived in external galaxies with IFU surveys. Finally, I will also discuss future observations of the FIR lines that can fundamentally improve our understanding of the impact of stellar feedback in the regulation of star formation in galaxies with the ASHTROS suborbital balloon and future FIR space-based missions.

7.7μm PAH Star Formation Rate Calibration with JWST MIRI

Kaila Ronayne
Texas A&M University

We test the relationship between (dust-corrected) UV-derived star formation rates (SFRs) and the 7.7 μm polycyclic aromatic hydrocarbon (PAH) luminosities from the integrated emission of galaxies at z = 0-2. We utilize multi-band photometry covering 0.2 - 160 μm from HST, CFHT, JWST, Spitzer, and Herschel for field galaxies in the Cosmic Evolution Early Release Science (CEERS) Survey. We perform spectral energy distribution (SED) modeling on the galaxies and use these results to measure dust-corrected UV-based SFRs. We also model the JWST/MIRI 7.7-21 μm CEERS imaging to derive a rest-frame 7.7μm luminosity using the average flux density in the rest-frame MIRI F770W bandpass (L770). We observe a correlation between L770 and the dust-corrected FUV luminosities, which diverges for varying galaxy properties such as low metallicity/obscuration as well as evolved stellar populations. Using the correlation between L770 and the dust-corrected FUV, we derive a single-wavelength SFR calibration to estimate the total SFR from the rest-frame 7.7μm luminosity. The SFR estimates from the single-wavelength calibration correlates with SED-model estimated SFRs with a scatter of 0.24 dex. We find that the total SFR can be approximated with the obscured SFR derived from the 7.7μm luminosity for massive and optically thick galaxies. We also derive a multi-wavelength calibration, which considers the total SFR to be a combination of the obscured and unobscured SFR, for the dust-corrected FUV luminosity using a linear-combination of the rest-frame observed FUV and 7.7μm luminosity. The SFR estimates from the multi-wavelength calibration correlates with SED model SFRs with a scatter of 0.23 dex. We find that the uncertainty in the multi-wavelength calibration increases for galaxies with low metallicity/obscuration, where the 7.7μm luminosity is not tracing the obscured SFR.

The Unsettled Youth of Galaxies: Understanding Bursty Star Formation in Galaxies at Cosmic Dawn

Guochao Sun
Northwestern University

The James Webb Space Telescope (JWST) provides an exemplar for how theories can be tested by novel observations. Of the many exciting new results from JWST, the likely prevalence of galaxies with bursty star formation at cosmic dawn has attracted much attention, which is suggested both by detailed analysis of the observed galaxy SEDs and by the number density of UV bright galaxies. In this talk, I will discuss the insights from state-of-the-art cosmological simulations of galaxy formation produced by the Feedback in Realistic Environments (FIRE) project, where spatially clustered and temporally bursty star formation naturally occurs in high-z galaxies. I will describe the theoretical landscape of this phenomenon of bursty star formation by introducing its physical drivers and implications for a variety of observables, including galaxy-scale properties and several large-scale effects. I will present results from a few ongoing projects on (1) better understanding the physical connection between bursty star formation and the star formation efficiency in galaxies at cosmic dawn, and (2) forward modeling bursty star formation histories with both parametric and generative AI approaches in fully Bayesian frameworks.

Katachi (形) : Decoding the Imprints of Past Star Formation on Present Day Morphology in Galaxies

Juan Alfonzo
Tohoku University

The physical processes responsible for shaping how galaxies form and quench over time leave imprints on both the spatial (galaxy morphology) and temporal (star formation histories (SFHs)) tracers that we use to study galaxies. While the morphology-SFR connection is well studied, the correlation with past star formation activity is not well understood. To quantify this connection and study it further, we present Katachi (形) – an interpretable convolutional neural network (CNN) framework that learns the connection between the factors regulating star formation in galaxies on different spatial and temporal scales without invoking assumptions about parametric morphologies or SFHs. The networks are trained on 9904 galaxies in the SDSS-IV MaNGA DR17 sample with $0.02<z<0.1$ to predict stellar mass (M_*; RMSE 0.22 dex), current star formation rate (SFR; RMSE 0.75 dex) and the cosmic time at which half of star formation occurred (t_{50}; RMSE 0.28 dex). This information allows us to reconstruct non-parametric SFHs for each galaxy using the dense basis method from gri imaging alone. To quantify the morphological features connected with a galaxy's SFH we use SHAP (SHapley Additive exPlanations) to interpret the mappings learned by the network to make its predictions. We recover the expected trends of $M*$ governed by the growth of galaxy bulges, and SFR correlating with spiral arms and other star-forming regions. We find that t50 tends to focus on a combination of the two. Katachi (形) additionally serves as a public framework to predict galaxy properties from large imaging surveys including Rubin, Roman, and Euclid.

Gravity or turbulence? Understanding the star formation law from molecular clouds to galaxies.

Javier Ballesteros-Paredes
Instituto de Radioastronomía y Astrofísica, UNAM, Campus Morelia

In this talk, I will show that the variety of Kennicutt-Schmidt (KS) relations reported in the literature, from molecular clouds in the Milky Way (MW) to resolved and unresolved galaxies, is naturally explained by the very collapse of the molecular clouds. I will also show that the low values and the constancy of the (wrongly named) "efficiency per free-fall time" arise naturally when the clouds collapse. Putting all together, our results imply that star formation is fast and efficient and that molecular cloud turbulence, the pressure in the midplane of the galaxies, their rotation, or other physical agents are not the primary drivers of the star formation law but only slight modification over the main law, namely, that the star formation rate is proportional to the mass in collapsing gas. However, stellar feedback is crucial to halt star formation, keeping the gas depletion time low on galactic levels. I will show, finally, that these KS relations are consistent with numerical simulations of collapsing clouds.

Wind and Fire: Resolving the multi-phase ISM of M83 with JWST

Logan Jones
STScI

A complete understanding of stellar feedback in galaxies requires an accurate characterization of recent generations of stars (traced by ionized gas or stellar populations) and of the molecular gas in star-forming regions. With the advent of high-sensitivity mid-IR spectroscopy on JWST, both the ionized and molecular gas can be characterized simultaneously, revealing the interplay between massive stars and different ISM phases at resolutions of ~a few pc even in external galaxies. We thus present a mid-IR view of the physical conditions and excitation mechanisms in the ionized gas and warm molecular gas (H2) in the core of the nearby spiral galaxy M83. Our MIRI/MRS observations cover the central ~200 x 200 pc of M83 at scales of ~3 - 16 pc, allowing us to spectroscopically examine its multi-phase ISM at unprecedented resolution. We show the line emission maps and kinematics of prominent low- and high-ionization species (e.g., [Fe II], [Ne III]), including possible outflows traced by the high-ionization lines. We use line ratio diagnostics to map the SFR and ionization parameter across our FOV, as well as disentangle the importance of shock- vs. starburst-driven excitation on a pixel-by-pixel basis. Finally, we present the results of our H2 excitation modeling and examine correlations between the warm H2 column and excitation and the physical properties of the ionized gas. When combined with archival far-UV spectroscopy of young, massive star clusters from HST/COS, this work will allow us to understand how the fuel for future generations of star formation is affected by massive star feedback in a starbursting environment.

Star Formation Rate Estimation using Self-Organizing Maps for Large Dataset Surveys

Valentina La Torre
Tufts University

Understanding the drivers of star formation across galaxy populations at all redshifts is crucial for studying galaxy evolution. However, accurately extracting star formation rates (SFR) from large survey datasets remains a computational challenge. We explore the use of Self-Organizing Maps (SOMs), an unsupervised machine learning (ML) technique, to efficiently derive SFR and other stellar population parameters for millions of galaxies in the Hyper-Supreme Cam (HSC) Deep survey. SOMs pre-classify galaxies based on their colors and therefore their underlying properties and redshifts. This enables rapid SFR estimation via a post-training phase that includes calibrating the SOM. We demonstrate that this method has the best balance between accuracy and computational cost compared to other ML methods, and it is over a million times faster than traditional methods. This approach has the potential to be applied to upcoming large surveys, such as LSST and Euclid, enabling comprehensive studies of star formation across cosmic time.

The imprint of star-formation-driven outflows on the evolution of nearby dwarf galaxies

Michael Romano
National Centre for Nuclear Research, Warsaw, Poland

Feedback from stars and active galactic nuclei is one of the most important processes steering the baryon cycle in galaxies, i.e., the set of complex phenomena driving the interplay between gas, dust, and star formation in their interstellar medium (ISM). Such a feedback could be strong enough to produce galactic-scale outflows able to sweep the gas out of the galaxies, drastically shaping their evolution. We investigated the impact of star-formation-driven galactic outflows in a sample of local low-metallicity dwarf galaxies drawn from the Dwarf Galaxy Survey. We made use of Herschel observations to detect atomic outflows in the high-velocity wings of [CII] 158 um emission line profiles. We found strong evidence of outflowing gas in 1/3 of the galaxies, with an average mass-loading factor (i.e., outflow efficiency) of the order of unity. We estimated that ~40% of the gas entrained by the outflows can be pushed away from the ISM, significantly enriching the surrounding circumgalactic medium, and producing extended atomic gas reservoir around the galaxies. These results highlight the importance of feedback in the baryon cycle of low-mass sources, and are crucial for calibrating state-of-the-art chemical evolution models attempting to reproduce the processes ruling the evolution of these galaxies across cosmic time.

Star formation at low metallicities – from massive OB stars to YSOs in the SMC star cluster NGC 602

Peter Zeidler
Space Telescope Science Institute

Star formation (SF) processes are influenced by the larger, yet local environment in which these stellar systems form. In turn, the newly born stars, which are typically located in young star clusters (YSCs), impact their natal Giant Molecular Cloud. Pre-supernova feedback processes expose the YSCs, erode the surrounding molecular clouds, create photodissociated regions, and are believed to drive SF into the surrounding gas and dust shell. The most detailed, high-resolution studies of star forming regions have been conducted in the Milky Way thus do not provide the diverse environments that are required to understand SF processes throughout the Universe. We present a multi-instrument (HST, JWST), multi-wavelength (FUV to mid-IR) study of NGC 602 in the Small Magellanic Cloud (SMC), the low-metallicity counterpart of Trumpler 14 in the Carina Nebula, hosting numerous centrally concentrated O and B stars and is a unique example for SF in isolation. The SMC provides the closest stellar laboratory with conditions more similar to the Cosmic Noon and with the wavelength coverage, sensitivity, and resolution of HST and JWST, opens a window into the early Universe. In our multi-wavelength study, we quantify the FUV fluxes and stellar winds of the massive cluster stars using HST STIS spectra and characterize the cluster kinematics with optical multi-epoch Hubble photometry. The over 22000 detected sources in the region using JWST include the disk-bearing pre-main-sequence stars and reveal the young stellar objects deeply embedded in the surrounding HII region, thus allowing us to investigate SF on all scales.

Mapping multi-phase mixing of metals in Star Forming Galaxies

Valentina Abril Melgarejo
Space Telescope Science Institute

Metals are fundamental components of galaxy evolution, they regulate the cooling of gas and the transport of momentum, enhancing/quenching star formation. Despite this essential role, we have a poor understanding of how metals are distributed among different gas phases through a galaxy. Chemical inhomogeneities have been detected in the ionized gas of numerous star forming galaxies (SFGs) via spatially resolved studies. Recent HR hydrodynamical simulations have opened crucial questions on mixing timescales and the presence of localized enrichment between the two gas phases. In this talk I present the first spatially-resolved multi-phase gas abundance study of a metal poor high-z local analogue, targeting 10 star-forming (SF) regions with COS and co-spatial optical VLT/MUSE observations. We have inferred neutral gas abundances for 13 different ions sampling 8 elements and compared them with the ionized gas abundances, measured along the same sightlines. By exploring metal distribution as a function of age, radius and gas phase, we have pinned down the mixing timescales between the neutral and ionized gas phases. The findings of this pioneering study are applicable to both nearby and high-z SFGs, expanding the potential of multi-phase analysis to the high redshift universe in the era of JWST.

Dust Attenuation of Star Forming Regions in Nearby Galaxies and the Swift+MaNGA Value Added Catalog

Laura Duffy
Pennsylvania State University

Accurate measurements of extragalactic star formation rates (SFRs) are crucial in constraining galaxy evolution. SFR measurements are complicated, however, by the presence of dust. Furthermore, the effects of dust can vary both from galaxy to galaxy and within a galaxy itself. In this work, we investigate this variation by using resolved, kiloparsec-sized star forming regions in 29 nearby galaxies to constrain a number of properties related to dust attenuation, including the infrared excess and the UV spectral slope (the IRX-β relation), as well as the gas-phase metallicity. The data set we employ includes UV photometry from Swift/UVOT, IR photometry from WISE, and IFU spectroscopy from SDSS-IV/MaNGA. We find that the dust attenuation seen in the star forming regions follows largely the same laws as seen in the galaxies as a whole and that, on these scales, the gas-phase metallicity is highly correlated with both the infrared excess and the UV spectral slope. This correlation between metallicity and IRX suggests that regardless of aperture, metal-rich regions have steeper attenuation curves. We also advertise the updated Swift+MaNGA (SwiM) Value Added Catalog , an earlier version of which was used to perform this analysis.

Characterizing Fine Metallicity Fluctuations Across Galactic Structures with SIGNALS

James Garland
David A. Dunlap Department of Astronomy and Astrophysics, University of Toronto

Galactic disks have been known for some time to exhibit negative radial abundance gradients, in line with an "inside-out" model of galaxy growth. However, dynamical processes, especially those associated with nonaxisymmetric features such as bars and spiral arms, can lead to varied mixing of metal-rich gas throughout the disk. Indeed, subtle azimuthal variations in metallicity on the order of 0.01-0.1 dex can reveal the intricate flow of enriched gas through galaxies. To observe such fine chemical fluctuations, we turn to the Star formation, Ionized Gas, and Nebular Abundances Legacy Survey (SIGNALS), a program that imaged over 50,000 H II regions in 31 nearby galaxies on spatial scales down to ~1 pc and spectral resolutions of R = 5000. We examine the 4,285 emission line regions recorded in the face-on grand design spiral galaxy NGC 628. Simultaneously fitting each region's emission line fluxes to a large grid of photoionization models yields well-constrained chemical abundances. We fit our measurements to model grids in the Mexican Million Models database (3MdB) which reflect an expansive parameter space of physical conditions. To obtain a robust quantification of galactic structure, we use novel machine learning models trained on morphologically classified galaxy images to construct a weighted map that smoothly delineates arm and inter-arm regions. Together, these precise abundances and morphological classifications form a powerful probe of the subtle chemical fluctuations associated with galactic structures. In this poster, we highlight the azimuthal trends measured in NGC 628 and compare approaches to quantifying local variations.

SIGNALS: The Star-formation, Ionized Gas, and Nebular Abundances Legacy Survey

Laurie Rousseau-Nepton
University of Toronto

October 2018 marked the beginning of a new large program at the Canada-France-Hawaii Telescope: SIGNALS, the Star-formation, Ionized Gas, and Nebular Abundances Legacy Survey. During five years and with 63 nights of telescope time in hand, our collaboration observed almost all the extragalactic HII regions within a distance of 10 Mpc using the Imaging Fourier Transform Spectrograph (IFTS), SITELLE. The goal: to get spectral information over the strong emission lines of the visible (i.e. [OII]3727, Hbeta4861, [OIII]4959,5007, [NII]6548,6583, Halpha6563, HeI6678, [SII]6716,6731) with a spectral resolution of 5000 (on Halpha) at a mean spatial resolution of 20 parsecs over as many HII regions as possible while covering uniformly different environments. SITELLE, with its FOV of 11 arcminutes and its 4 million spaxels, is the perfect instrument for such a survey. In order to build a sample of more than 50,000 HII regions located in different galactic environments, SIGNALS covered 31 galaxies that are actively forming stars, with various mass, morphology, and abundances. Along with ancestry data in the IR and UV, our collaboration aims at studying resolved star-formation activity, understanding the impact of the local environment on the star-formation process, and providing the science community with a unique dataset along with new tools to study star formation. This poster will introduce this ambitious project and show some preliminary results.

Molecular gas in low metallicity galaxies and its implications for star formation

Ava Polzin
The University of Chicago

We present a new, simple model to describe the fraction of molecular hydrogen gas in low metallicity galaxies, which can be applied to both local, low mass dwarf galaxies and galaxies at high redshift where the global metallicity is lower. Our model takes into account gas density, metallicity, and the strength of the ionizing radiation field, and accurately predicts the abundance and mass of molecular hydrogen in low metallicity galaxies when applied to three-dimensional grid cells and to projected maps that are smoothed on large scales. We find that the star formation rate is not directly tied to the amount of molecular hydrogen in low metallicity galaxies, implying that star formation occurs in cold neutral gas generally, rather than molecular gas specifically. This suggests that molecular hydrogen-based star formation prescriptions miss this reservoir of star-forming material by default. We briefly discuss the implications of this additional reservoir for simulations of low metallicity galaxy evolution. We have also developed a model for the fraction of star-forming gas in low metallicity galaxies calibrated on the properties of the ISM, which can be used in low-resolution simulations and semi-analytic models of galaxy formation.

Physical Conditions of Gravitationally Lensed Galaxies with JWST

Brian Welch
University of Maryland/NASA Goddard Space Flight Center

Gravitational lensing magnifies distant galaxies, enabling observations of smaller spatial scales and of intrinsically fainter objects than would be visible in field galaxies. Combining lensing with JWST imaging and spectroscopy enables detailed studies of the physical conditions within distant galaxies, which can shed light on the processes that drive galaxy evolution over cosmic time. I will present results from several JWST observing programs studying lensed galaxies, particularly highlighting three recent results. I will discuss recent NIRCam imaging of the Cosmic Gems arc, the most distant lensed arc known at z = 10.2. This arc hosts multiple compact star clusters (r ~ 1pc) which appear to be gravitationally bound, indicating that these are likely nascent globular clusters forming in the early universe. Second, I will present NIRSpec MOS spectroscopy of parsec-scale star clusters in the Sunrise Arc at z~6. This galaxy hosts both young massive star clusters with strong nebular emission line features, and older globular cluster precursors lacking significant emission lines. Finally, I will present recent NIRSpec detections of multiple auroral emission lines in a lensed galaxy at z = 1.3, which have enabled direct chemical abundance measurements in this distant galaxy. Together, these JWST observations are providing a more detailed picture of the evolution of galaxies over cosmic time.

Chemical Evolution Near and Far: Abundance Patterns in the JWST Era

Karla Arellano Cordova
University of Edinburgh

Nebular emission lines are powerful diagnostic tools for tracing the chemical enrichment in star-forming galaxies (SFGs) across cosmic time. We use the COS Legacy Spectroscopy SurveY (CLASSY) of local SFGs spectra to study the abundance patterns of N, Ne, S, Cl, and Ar. With a robust determination of the physical conditions and gas-phase abundances we study the Ne/O, S/O, Cl/O, and Ar/O ratios in concert with metallicity. We report that the abundance ratios of these elements follow a constant behaviour with metallicity as expected by nucleosynthesis for values below the O/H solar abundance. The Ne/O and Ar/O vs. O/H relations show a strong correlation as metallicity increases, while the S/O and Cl/O patterns show significant offset at lower values in comparison to their solar abundance values. These results could arise from the poorly constrained systematic corrections for unobserved ion species. We assess the scatter involved in the N/O vs. O/H relation and its connection with the different galaxy properties to explore the super solar values observed in early galaxies. We use CLASSY as a useful reference to evaluate the cosmic of evolution of Ne, S, and Ar of z>4 galaxies. We confirm no redshift evolution of Ne/O and stress that the lack of direct temperature-based abundances of S/O and Ar/O at z >4 can bias our interpretation of their cosmic evolution. The abundance patterns of CLASSY and their broad range of physical properties provide a benchmark to interpret the chemical enrichment of high redshift galaxies observed with the JWST.

The Circumgalactic medium of Lyman-alpha emitters at z~3.3

Eshita Banerjee
IUCAA

Based on the current consensus, the inward and outward flows of baryons driven by accretion and galactic winds, known as the "cosmic baryon cycle'', dictate the formation and evolution of galaxies. The Circumgalactic medium (CGM) contains the imprints of these crucial yet poorly understood processes that are believed to play a key role in shaping the cosmic star formation rate density which peaks around redshift (z) ~2-3. For this quest, the MUSE Quasar-field Blind Emitters Survey (MUSEQuBES) is dedicated to studying the CGM of 96 z=3.3 Lyman-alpha Emitters (LAEs) using bright background quasars. Our work employs a detailed Voigt profile decomposition of absorption lines in quasar spectra associated with the LAEs. So far, our findings include: (a) No discernible trend found between HI and CIV column density and impact parameter (ranging 16-300 kpc), indicating a clumpy nature of the CGM at these redshifts. (b) The ''group'' environments are both gas and metal rich as in the LAEs in group environments exhibit higher HI and CIV covering fractions compared to the isolated ones. (c) Neutral gas-rich galaxies, identified by their rest frame equivalent widths of Ly-a emissions, show higher HI covering fractions in their circumgalactic medium. (d) The Lyman limit systems are predominantly found at larger (>50 kpc) impact parameters, likely due to the non-detection of faint absorber-hosts. (e) Using the covering fraction profile, the LAE-CIV absorber two-point correlation function is constrained, revealing that high column density CIV absorbers serve as effective tracers of galaxy halos.

Tracing metals in and around galaxies with the MUSE Ultra Deep Field

Alexander Beckett
STScI

Star formation is regulated by the exchange of gas between galaxies and their circumgalactic medium (CGM), known as the baryon cycle. The cool gas required to form stars is accreted from the CGM onto galaxies, and can be heated and ejected by supernovae (or AGN). This drives the fundamental metallicity relation (FMR) between galaxy mass, metallicity and star-formation rate. The distribution of metals in the CGM can be used to constrain our models of feedback and recycling, but observing this gas remains challenging.

We utilize the MUSE Ultra Deep field (MUDF), comprising VLT/UVES spectroscopy of two bright quasars at z~3.2, alongside ~150 hrs of MUSE observations, ~90 orbits of HST grism spectroscopy, and deep HST imaging across multiple bands. These highly sensitive datasets allow us to detect absorption from metal-enriched gas down to ~0.02 Angstrom equivalent width and measure galaxy metallicities and orientations at stellar masses as low as ~10^7 solar.

I will describe analysis of the MUDF showing that CGM properties depend on azimuthal angle around galaxies with high star-formation rates, likely indicating outflowing and accreting structures and suggesting that star formation is the main driver of the baryon cycle for these galaxies. We find galaxies with CGM absorption at z<2.4 are not systematically offset from the FMR, consistent with absorption tracing the same feedback processes as those encoded in the FMR. Future JWST observations are needed to directly compare gas and galaxy metallicities at higher redshifts, allowing us to fully trace the cycle of metals through galaxies.

Imaging the Circumgalactic Medium with the Dragonfly Spectral Line Mapper

Seery Chen
University of Toronto

The Dragonfly Spectral Line Mapper (DSLM) is a new instrument designed to directly image the circumgalactic medium of local galaxies in H-alpha, [NII], and [OIII] emission. With a wide field of view of 1.4x1.9deg encompassing the virial radius of most nearby galaxies, a resolution of order kpc, and a capability of reaching surface brightness limits of ~10^-20 erg/s/cm^2/arcsec^2, DSLM breaks ground on a new era of ultra low surface brightness emission line imaging. Data from DSLM will provide a “big picture” point of view to investigate the morphology of the diffuse ionized circumgalactic medium around individual galaxies, and the structure of inflows and outflows, extending the study of the CGM in emission down from the higher redshifts covered by IFUs such as KCWI and MUSE to the local universe. DSLM surveys have started in January 2024 and expect science data on the first targets to be ready in March 2024. Here we give a brief overview of the DSLM instrument and survey design. We present preliminary data from our commissioning phase including some of the deepest wide field emission line imaging to date, on galaxies NGC 3079 and NGC 891.

Stellar Feedback Clears the Path to Cosmic Reionization

Sophia Flury
University of Massachusetts Amherst

Observations such as the Gunn-Peterson trough indicate that the Universe reionized by a redshift of z~6. However, we cannot directly identify the galaxies responsible for this dramatic change in the intergalactic medium (IGM) because the ionizing photons involved were lost in the process of Reionization. Instead, we must rely on observations of ionizing radiation (Lyman continuum or LyC) from nearby (z~0.3) star-forming galaxies analogous to galaxies at z>6 in order to establish observational proxies for LyC escape at high redshift. I will present the Low-redshift Lyman Continuum Survey (LzLCS), a large HST/COS program with the most local LyC measurements of star-forming galaxies to date, to investigate LyC escape at z~0.3. With the LzLCS results, I will illustrate which nearby analog galaxies are the most significant LyC emitters (LCEs) and which stellar feedback mechanisms facilitate LyC escape into the IGM at z~0.3. Using ground-based observations of galaxies at z=2-5 from VANDELS and the new wealth of JWST observations of many z>6 galaxies (including CEERS, JADES, and NGDEEP), I will demonstrate how to extend insights from LCEs at z~0.3 to higher redshift to determine LyC escape fractions, the critical variable in determining how star formation and star-forming galaxies contribute to cosmic reionization.

Revealing cosmic systems: exploring giant, optically emitting, circumgalactic nebulae

Will Liu
University of Michigan, Ann Arbor

Gas inflows from the circumgalactic medium play a key role in governing galaxy evolution by fuelling star formation and black hole growth. Simultaneously, gas outflows are driven to the CGM by supernovae and AGN activity. Thus, the CGM offers a unique perspective for exploring the cosmic systems that shape galaxy evolution. Based on deep integral field spectroscopy with MUSE, I will present results from studying two giant nebulae at z~0.6. The first nebula surrounds quasar HE0238-1904, which resides in an unusually overdense environment for a radio-quiet system. The environment likely consists of two groups which may be merging. The nebula exhibits largely quiescent kinematics and irregular morphology. The nebula primarily arises from interaction-related stripping of CGM/ISM of group members. The upper limits on the electron number density implied by the [O II] doublet ratio are consistent with CGM or ISM origin. However, the densities implied from the measured line ratios between different ions (e.g., [O II], [O III], and [Ne V]) and photoionization simulations are often 10−400 times larger. This large discrepancy can be explained by long-term (10^4-10^5 years) quasar variability which can produce non-equilibrium effects in the CGM. The second nebula surrounds quasar 3C57, a radio-loud quasar residing in a local system hosting 7 group galaxies. The nebula exhibits multi-component emission features, consistent with expectations from a biconical outflow. These systems offer an exceptional opportunity to explore the influence of AGN outflows and group interactions on these galactic environments.

A kpc-view of the CO, [CI] and dust emission in and around a starbursting AGN-host galaxy at z~2.6

Allison Man
The University of British Columbia

Exactly how AGN feedback regulates star formation remains challenging to study, due to the lack of observations for how AGN affects gas across a range of phases, temperatures and densities. In this talk, I will describe a decade-long effort to study the multi-phase gas flows in one of the most extreme star-forming, radio AGN-host galaxies at cosmic noon based on observations spanning UV through radio. Using deep, multi-band, and high-resolution (1 kpc) ALMA observations, we detect the inner rotating molecular gas disk embedded in the AGN host galaxy, accompanied by an extended tail indicating possible gas inflow or outflow, with clear evidence for non-circular motions. The extended gas tail is largely devoid of dust continuum emission and is highly excited compared to the ISM in the host galaxy, as indicated by the elevated CO(7-6)/CO(4-3) and [CI](2-1)/[CI](1-0) emission line ratios. Based on the kinematics and the inferred physical properties of the gas in the host galaxy and the extended tail, I will discuss the plausible origins of the gas tail and its relation to the established ionized gas outflow and radio jets in the galaxy. The spatially resolved spectral line ratio analysis of this well-studied target presents an opportunity to advance ISM/CGM modelling and its application in constraining the role of AGN and stellar feedback in regulating star formation at cosmic noon.

Setting analytic prescriptions ablaze: Machine-Learnt Star-formation laws with FIRE-2

Diane Salim
Rutgers University

Whilst star formation is critical for understanding the evolution of galaxies, the physical processes that determine it remain nebulous. Physicists have always sought out closed-form symbolic expressions that connect physical variables to natural phenomena. However, finding such mathematical expressions is difficult and, to date, has not been possible for turbulence and related problems such as star formation. Such uncertainty has given rise to a multitude of different star formation laws, all exhibiting substantial intrinsic scatter. In this work we tie together such analytic descriptions of star formation in the interstellar medium (ISM) and understanding what drives turbulent star formation with recent advancements in machine learning techniques. In particular, we will use neural network symbolic regression (SR) techniques to produce the first machine-learned star formation analytic relations. We employ PySR, a supervised machine-learning SR technique based on genetic algorithms that assembles analytic functions to model a given dataset on publicly available FIRE-2 simulation suites, which has no explicit numerical sub-grid recipe for star formation. By training PySR with extracted variables from FIRE-2 galaxies such as the gas properties (e.g., surface densities, mass, sonic Mach number, virial parameter) and large-scale environmental properties (e.g., location of regions within a spiral galaxy, host halo masses, Toomre Q, gas fractions, circular velocities) we attain ML-generated analytic descriptions for how SFR depends on gas and galaxy variables and compare these new star formation recipes with classically-derived analytic models.

The baryon cycle in HI-selected galaxies at z~2

Grecco Oyarzun
Johns Hopkins University

The star-formation histories of galaxies are shaped by the baryon cycle. The rate at which galaxies form their stars is regulated by the balance between inflowing HI gas and outflowing metal-enriched warm/hot gas. In this talk, I will show how we probe the baryon cycle at z~2 by connecting measurements of HI gas in absorption with the population of galaxies detected in emission.

We find that HI-selected galaxies are diverse, with some featuring bright Ly-alpha emission and others showing bright CO emission in the sub-millimeter. This diversity is indicative of wide ranges of star-formation rates, stellar masses, molecular masses, and dust extinction. It is also becoming apparent that the properties of HI-selected galaxies may vary with the impact parameter and the metallicity of the HI gas. For instance, high-metallicity ([M/H]>-0.3) absorbers tend to feature more massive HI-selected galaxies, suggesting that the CGM of massive galaxies is already enriched at z~2. These results reveal that large numbers of HI-selected galaxies are needed to map the large parameter space in which the baryon cycle operates. In this context, I will discuss how highly sensitive telescopes and instruments launched in recent years will be essential for the identification and characterization of HI-selected galaxies in greater numbers.

Density vs. Destiny: the Lifecycle of Star-Forming Gas in FIRE-3

Dylan Benton
University of California, Merced

Stars form in cold clouds of predominantly molecular (H_2) gas, however, how cloud formation and lifetimes are coupled to star formation and the large-scale structure of the ISM remains an open question. Simulations provide a valuable tool for interpreting what is seen in these natal environments. In this poster I discuss the life cycle of gas in a Milky Way-mass FIRE-3 simulation. FIRE-3 imposes no density requirements for star formation to occur and includes multiple channels for stellar feedback. In addition, FIRE-3 boasts a superb ~parsec scale spatial resolution in a fully cosmological galactic environment, which makes it an ideal testbed. This enables detailed studies to characterize how gas density is connected to the star formation environment and how this relationship evolves with time. The "Density-Destiny" diagram is a new way to characterize the ultimate fate of gas in clouds in the ISM. I will present the first realization of this diagram in a cosmological simulation and show how it informs our understanding of the gas lifecycle in the context of star formation. I will draw comparisons to recently proposed analytical models and describe implications for the galactic environment's impact on density's predictive ability regarding future star formation.

Testing our ability to measure outflow properties and their impact on star formation with FIRE

Cody Carr
Zhejiang University

Understanding how galactic feedback influences the cessation of star formation (SF) as a function of galaxy type, redshift, and morphology are top goals for astronomers in the coming decades. Measuring the kinematic and geometric properties of galactic flows in high resolution spectroscopy will be essential for quantifying how feedback influences the surrounding environment to possibly prevent accretion (energy vs momentum transfer rates) and its efficiency to remove star forming material (mass loading factors): two primary quenching/starvation mechanisms. Unfortunately, current line interpretation models suffer from large systematic uncertainties, evident from the large differences between model predictions of basic quantities such as outflow rates. We address these issues by testing the ability of empirical and analytical techniques to recover the properties of galactic outflows in the FIRE simulation suite. I will present on our ability to measure the outflow rates of an intermediate mass ($\log[M^*/M_{sun}] = 9$) dwarf like galaxy simulation as a function of redshift ($0<z<0.7$) and as a function of radius ($r < 200$ kpc) using Si II and Mg II absorption lines. In addition, I will discuss our results using the tested radiation transfer models to analyze the outflows in CLASSY - a low-z UV study of highly SF galaxies with COS - and assess their potential to impact SF. Finally, I will comment on the current limitations of these techniques and how to overcome them with the next generation of instruments.

MUSEQuBES: A study of gas and metals around low-redshift galaxies

Sayak Dutta
Inter-University Centre for Astronomy and Astrophysics

We present a detailed study of gas and metals, traced by Lya and OVI, around low-redshift galaxies using absorption lines in background quasar spectra. Our galaxy survey with MUSE IFU (MUSEQuBES, around 16 bright background quasars), combined with the data from the literature, provides us with a sample of galaxy-quasar pairs with a large dynamic range of galaxy properties. Stacked Lya absorptions with ~5000 quasar-galaxy pairs and impact parameters (b) up to 3 Mpc provide insights into the boundary between the circumgalactic gas around galaxies and the large-scale structures. We find enhanced Lya absorption around low-mass galaxies outside the virial radius compared to their high-mass counterparts, which hints at the filamentary gas as the potential origin of this excess absorption. The line-of-sight profile of stacked Lya absorption in our work can be well explained by a simple galaxy-absorber two-point correlation function. The enhancement and depletion of Lya absorption inside the virial radius of star-forming galaxies and very massive galaxies (logM*~10), respectively, are also supported by the individual Voigt-decomposed Lya absorption studies around the homogeneous sample of MUSEQuBES galaxies. The individual absorption studies also provide insight into kinematically different circumgalactic gas around low-mass galaxies. The metals traced by individual OVI absorption around these galaxies suggest that the majority of OVI absorbers arise in the virialized halo of galaxies with logM*~9.5. However, we find a substantial fraction of OVI absorptions within the virial radius of low-mass (logM*<9) galaxies. The kinematics suggesting the gravitationally unbound nature of these OVI absorptions led us to speculate that these might be the remnants of hot outflows. Finally, stacking of OVI absorption for galaxies without associated OVI absorption revealed a diffused OVI halo outside the virial radius of low-mass galaxies with N(OVI) ≈ 10^13.2 cm^{-2}.

Effects of Active Galactic Nuclei Feedback on Galactic Morphology (Goddard, Shlosman, Romano-Diaz)

Julianne Goddard
Department of Physics and Astronomy, University of Kentucky

We use high-resolution cosmological zoom-in simulations to model the mechanical feedback from AGN onto evolution of galaxies. Specifically, we use a modified version of the hybrid hydro N-body code GIZMO with supernovae mechanical feedback to study morphology of galaxies immersed in dark matter halos with similar masses of log(M/Mo)~11.7 at redshifts z~3-0. Low mass, 10^6 Mo, seed black holes (SMBHs), have been introduced when the parent DM halos have reached log (M/Mo)~10.9. The SMBH seeds have evolved to few x10^7 Mo at z=0 by accretion and produced collimated jets, ejecting 10% of the mass accretion rate. The accretion rates onto the SMBHs have been calculated by means of gravitational torques with an added efficiency of 4.5%, 15% and 50%. The resulting accretion rate onto the SMBHs varied as ~0.3-10^{-3} of the Eddington accretion rate. We have compared basic properties of the central galaxies, such as the star formation rate, masses, gas and stellar fractions, bulge-to-disk mass ratios, SMBH masses, etc., over the range of redshifts. Our results indicate that the AGN feedback with the Seyfert-type nuclei has a profound effect on galaxy evolution, including the physical and thermodynamic properties of the circumgalactic medium (CGM), which extends from the central galaxy to a few x Rvir, where Rvir is the halo virial radius. Furthermore, we evaluated the Sersic profiles of the central galaxies and their half-mass radii to quantify the effect on the galactic morphologies. We also find that despite different evolutionary tracks, some galactic properties tend to converge at z=0.

HI's Role in regulating global and local SFR in the Virgo Cluster

Celine Greis
McMaster University

The Virgo Cluster, a young cluster with a high fraction of star-forming spirals, is a great laboratory for studying environmental effects on star formation and gas properties. On a global scale, we find that H2-normal Virgo cluster galaxies with high atomic gas deficiencies show low star formation rates. That is startling. Does the lack of HI stop cluster galaxies from forming stars efficiently? Using kpc-resolution VERTICO CO data, we study resolved star formation relations of Virgo cluster galaxies. They reveal that HI surface densities drive the scatter of the star-forming main sequence. Regions with elevated HI content show higher star formation rates. Field galaxies in the HERACLES sample do not exhibit the same trend. Similarly, we find that the scatter in the Kennicutt-Schmidt relation is primarily driven by low molecular-to-atomic gas surface density ratios (Rmol). Lower Rmol values show higher star formation rates. Again, that trend isn't visible in the HERACLES sample. We plan to investigate the connection between the dynamical equilibrium pressure, Ram pressure, and our findings in the future.

Star Formation at the Lowest Densities: Starbursts in Diffuse Environments

Chris Mihos
Case Western Reserve University

I present results from two recent Hubble Space Telescope studies of star formation in low density environments: in the outer disk of the spiral galaxy M101, and in the extreme ultradiffuse galaxy BST1047+1156 in the Leo I Group. In both objects the gas density is extremely low, below the threshold at which star formation is thought to be suppressed in galaxies. We have conducted deep imaging to resolve the stellar populations in both these systems, and find evidence for evolving post-starburst populations indicative of recent starburst activity in both systems, despite their low gas densities. We use stellar population synthesis techniques to constrain the metallicity and age of these populations, and tie their origins to dynamical processes associated with interactions in the group environment of their host galaxies. In both cases, these young stars are destined to be stripped and dispersed into the surrounding volume, demonstrating how this diffuse mode of star formation can feed young stars into the circumgalactic/intragroup environment.

Resolved studies of galactic outflows at Cosmic Noon

Keerthi Vasan
University of California, Davis

Galaxy formation is regulated by the ejection of large-scale "outflows" of gas from their interstellar medium (ISM), driven by energy released from star formation and/or accretion onto supermassive black holes. These outflows can be studied at high redshifts via absorption line kinematics, but obtaining good velocity resolution is challenging. I will discuss results from our kinematic study of outflowing gas viewed "down the barrel" in 20 gravitationally lensed galaxies at $z\sim2-3$ observed with Keck/ESI and archival

Magellan/MagE, where lensing magnification enables good signal-to-noise and spectral resolution ($R\sim4000$; FWHM$\sim$75 km$\,$s^{-1}). We find that the bulk motion of the ISM gas at this epoch is outflowing with a median velocity centroid of $v_{cent}=-148$ km$\,$s^{-1}. However, the ISM gas exhibits a diverse range of velocity profile characteristics, which is not apparent at lower spectral resolution. The velocity profiles show a distinct high-velocity blueshifted tail of outflowing gas with varying skewness extending up to -500 km$\,$s^{-1} (i.e., $\gtrsim3\times v_{cent}$) and velocity widths of $\Delta v_{90}\sim600$ km$\,$s^{-1} larger than those seen in quasar sightlines. We find evidence that this outflowing gas seen in absorption likely traces gas at small radii (i.e., $r\lesssim 10$kpc), and scaling relations between the obtained outflow velocities with galaxy stellar mass and star formation rate (SFR) are consistent of a momentum driven wind scenario. This work highlights the importance of well-resolved outflow velocity structure and represents the largest available benchmark sample at $z > 2$. I will also discuss our outflow kinematic results obtained from Keck/KCWI of a lensed, star-forming galaxy at $z\sim2$, where the spatial information enables us to characterize the spatial structure of outflow velocity and reliably measure the mass loss rate and mass loading factor for the low-ionization outflowing gas in this galaxy.

Failed AGN feedback? -- Molecular reservoirs are not severely affected by extreme AGN ionized-wind

Xiaoyang Chen
National Astronomical Observatory of Japan, ALMA Project

Large-scale outflows are generally considered as a possible evidence that active galactic nuclei (AGNs) can severely affect their host galaxies. Recently several ultraluminous IR galaxy (ULIRG) selected from AKARI FIR catalog was found to have galaxy-scale [OIII] 5007 outflows with extremely high energy-ejection rates compared to active galaxies at z<2. However, the latest ALMA follow-ups of these galaxies reveal that the molecular reservoirs are not severely affected by the fast ionized AGN wind. The velocity of the molecular outflow is slower by one order of magnitude than that of ionized-wind, indicating that the outflowing molecular gas could not escape from the gravitational potential of these galaxies. The finding suggests that the feedback effect on star-forming clouds in hosts could be limited even with extremely fast and powerful AGN ionized-outflows, which is consistent with the vigorous starbursts in the galaxies, i.e., with SFR of 1000 Msun/yr.

Title TBD

Allison Erena
University of Wisconsin-Madison

Much of the processes of galaxy formation at higher redshift remain a mystery. In particular, we aim to learn how massive galaxies in the early Universe underwent quenching after a period of extremely high star formation. To better understand the mechanism behind this, we examine a subset of five low-redshift (z<1) galaxies that serve as analogs for those at higher redshift. These galaxies have been shown (e.g. in Sell+ 2014) to be extremely compact, and all are in the final throes of major dissipational merger events. This poster focuses on one galaxy in our sample, nicknamed Makani for its impressive gas outflow structures that are thought to involve up to a third of the galaxy's total gas mass (Geach+ 2014, Rupke+ 2019). We utilize JWST's Mid-Resolution Spectrograph on the Mid-IR Instrument (MIRI) to probe for the source of these extreme galactic winds. Preliminary results indicate that an active nucleus (one of the main suspects) is an unlikely driving mechanism, in consideration of forbidden neon lines and PAH complexes.

Dual AGN fractions in galaxy mergers and implications for SMBH growth

Mason Footh
The University of Alabama

Tight scaling relations like the Magorrian relation suggest a link between the growth of supermassive black holes (SMBH) and that of their host galaxy. SMBH growth by accretion (i.e. triggering an Active Galactic Nuclei or AGN) in mergers is predicted by theory, with accretion rates peaking somewhere around 0.1 to 10 kpc nuclear pair separation. Therefore, one would expect dual AGN (dAGN) to be relatively common, but observations have been few and far between. Only a few dozen with separations less than 5 kpc have been identified. This is likely due to the difficulty in identifying them. Alongside normal difficulties encountered in confirming AGN like obscuration and variable AGN luminosities, smaller separation (less than ~5 kpc) dAGN systems require exquisite spatial resolution, even at low redshift. In addition, the timescale for SMBH mergers are not well constrained with predictions varying by orders of magnitude. I will present results using a sample of ~205 dual nuclei (~175 visually identified close merging galaxy pairs and ~30 optically obscured but IR apparent duals in post-merger remnant galaxies) with separation < 5kpc from the Sloan Digital Sky Survey (SDSS). This represents one of the largest samples of ~kpc separation dual nuclei in existence. I will present results on the multi-wavelength AGN and dual AGN frequency in this sample, and constraints on the SMBH merger timescales derived from these systems. Time permitting, I will also discuss the importance of JWST for discovering and characterizing dual AGN.

The coevolution of star formation and SMBH accretion at Cosmic noon

Francesco Salvestrini
INAF - Astrophysical Observatory of Trieste

I will report a systematic study of a sample massive galaxies (M>10E10 Msun) at Cosmic Noon, that is the peak epoch of galaxy assembly and super-massive black hole (SMBH) accretion. Studying AGN and SF in this epoch is crucial to asses the role of AGN activity onto shaping the assembly of galaxies. In this context, millimetre observations are crucial as they trace the molecular gas, that fuels both SMBH accretion and star formation.

Here, I will present a collection of both archival and proprietary data from ALMA and NOEMA facilities in a sample of highly star forming galaxies (SFR~200-1000 Msun/yr), hosting luminous quasars. When compared with normal star forming galaxies with similar masses at the same epoch, quasars show higher star formation efficiency (by a factor of 10-100), suggesting that the host-galaxy growth is likely being regulated by quasar feedback, resulting in quenching timescales of few tens of Myr.

Furthermore, the high-angular resolution provided by interferometric facilities allows us to reveal that massive galaxies hosting luminous quasars reside at the center of rich systems with many companion galaxies. This validates the scenario where mergers may play a key role in the assembly of massive galaxies.

Evolution of Gas Flows along the Starburst to Post-Starburst to Quiescent Galaxy Sequence

Yang Sun
University of Arizona

Post-starburst galaxies are caught in a rapid transition between star-forming and quiescent galaxies, where the star formation ended in the last ~Gyr. While galactic feedback has long been recognized as an important contribution to galaxy evolution, and galactic winds are common in galaxies with starbursts or AGN, the role of such gas flows in galaxy evolution, especially in star formation quenching, remains uncertain. We examine how neutral galactic winds vary along a likely evolutionary sequence connecting starburst to post-starburst to quiescent galaxies for the first time. To detect the interstellar medium and measure its bulk flows, we examine the residual NaD absorption lines after the stellar contribution has been removed from each galaxy's spectrum. We discover that outflows diminish along this sequence, i.e., as star formation ends. Even within our post-starburst sample, the fraction of galaxies with significant winds and the average wind velocities decrease with post-burst age after controlling for stellar mass. We find most of the neutral outflows detected in post-starburst galaxies are not able to escape from the galaxies, suggesting those winds should play some other role in suppressing star formation than cleaning up the cold gas. For the post-starbursts, We also find evidence for an AGN contribution, especially to the fastest outflows. However, for the starbursts, the outflow velocity has the inclination dependency, suggesting those winds are driven by star formation, not AGN.

Radio-AGN activity is not a direct function of host galaxy star formation rate

Arjun Suresh
New York University

Galaxy formation theories evoke radio-mode Active Galactic Nuclei (AGN) feedback to suppress star formation at high stellar masses. This motivates us to probe the relationship between radio-AGN activity and specific star formation rate (sSFR) of galaxies. We examine the demographics of radio-emitting active galactic nuclei (AGN) in the local universe as a function of host galaxy mass and sSFR. We use a sample of ~10,000 galaxies from the MaNGA survey of the SDSS-IV, in conjunction with the FIRST and NVSS radio surveys. We use star formation rate and stellar mass estimates based on Pipe3D, inferred from the high signal-to-noise ratio stellar continuum measurements from MaNGA. We show that these star formation rate measurements are strongly correlated with 20 cm radio emission, as expected. We identify as radio AGN those radio emitters that are much stronger than expected from the star formation rate. We find that the Eddington ratio distribution depends strongly on stellar mass, with more massive galaxies having larger Eddington ratios. Further, we do not find any dependence on star formation rate when controlling for stellar mass. That is, at fixed stellar mass, whether or not a galaxy is forming stars appears to be unrelated to the presence or absence of a radio-AGN. This result will inform subgrid models of large scale cosmological simulations. Further, it can help test the existing theoretical models of galaxy formation.

Rich and diverse molecular gas environment of dual quasars viewed by ALMA

Shenli Tang
University of Southampton

We observed 5 dual quasars with separations <20 kpc at z<1 with ALMA in cycle 8, mapping their CO J2-1 emission lines. Among the 10 quasars, we had > 5 sigma in-situ detection on 6 of them, and an offset detection on one source, where the CO center is shifted by ~10 kpc from the optical center. We estimated the CO luminosity and the total molecular gas mass of these systems, and compared with single quasars and inactive galaxies in literature, aiming to understand how AGN feedback would affect the molecular gas environment in such a specific phase of galaxy merger, and whether the existence of an extra AGN would make a difference.

Detecting Accreting Black Holes in Dwarf Galaxies: Emission Line Diagnostics for the JWST Era

Kristen Garofali
Johns Hopkins University

Understanding the demographics of intermediate mass black holes (IMBHs) is key to unraveling the formation and growth of supermassive black holes and the galaxies that host them. However, the search for IMBHs has proven difficult, in part because black holes in this mass range may be located preferentially in dwarf galaxies, which are typically more metal-poor and have more recent bursts of star formation than more massive galaxies. Searches at X-ray wavelengths for actively accreting IMBHs in dwarf galaxies (i.e., dwarf AGN) can be contaminated by X-ray binaries (XRBs), as luminous XRBs form efficiently in low-metallicity, star-forming galaxies. Nebular emission line diagnostics can help with the search for AGN in dwarf galaxies, but these line diagnostics are typically not calibrated considering the potential for contamination from the time- and metallicity-dependent XRB population. To that end, we present results from state-of-the-art photoionization simulations that include an IMBH ionizing contribution that varies with metallicity, and an XRB ionizing component that varies self-consistently with the stellar population as a function of time post-starburst and metallicity. These simulations suggest that luminous XRBs can contaminate line searches for AGN in low-metallicity dwarf galaxies when the AGN contribution to the ionizing photon rate is below 16%. Based on these results, we suggest best practices for using emission line diagnostics to select AGN in dwarf galaxies locally and at high redshift with JWST.

Black-hole positive feedback and galaxy formation in the early universe

Felix Mirabel
IAFE - University of Buenos Aires, Argentina & Lab AIM, CEA/CNRS/Université Paris-Saclay, France

Jets and massive outflows from black holes (BHs) can enhance ("positive feedback") or quench ("negative feedback") star formation, depending on the environmental conditions. Observations from the local universe up to redshifts of z = 4-5 show that positive feedback increases with increasing redshift, powerful radiogalaxies at the high redshifts producing ultraluminous starbursts of more than 10^12 solar luminosities. This is because positive BH feedback takes place by the impact of jets and massive outflows on high-density cold molecular clouds, which leads to rapid compression of the gas, and subsequent enhancement of star formation. Since the cosmic global gas density evolves with redshift z as (1+z)^3, this BH-jet triggering mechanism of star formation and galaxy growth must be important at the Epoch of Reionization (EoR) and cosmic dawn. In this context, AGN positive feedback may be one of the mechanisms that trigger the formation of large numbers of compact, bright and relative massive starburst galaxies at z > 5 observed by JWST. If supermassive BHs (SMBHs) of > 10^8 solar masses in quasars at z < 8 result from rapidly growing BH seeds form by direct collapse, BH positive feedback could be the mechanism that trigger the formation of the first stars and galaxies at cosmic dawn.

Powerful AGN Feedback Tied to Beads-on-a-String Star Formation in a Dynamically Active GalaxyCluster

Osase Omoruyi
Center for Astrophysics | Harvard & Smithsonian

With two central galaxies engaged in a major merger and a remarkable chain of 19 young stellar superclusters wound around them in projection, the galaxy cluster SDSS J1531+3414 (z=0.335) offers an excellent laboratory to study the interplay between mergers, AGN feedback, and star formation. New Chandra X-ray imaging has revealed rapidly cooling hot (T~10^6 K) intracluster gas, with two "wings" forming a concave density discontinuity in the central 100 kpc. LOFAR 144 MHz observations uncover diffuse radio emission strikingly aligned with the "wings," suggesting they are actually the opening to a colossal X-ray supercavity. The steep radio emission is likely an ancient relic of one of the most energetic AGN outbursts observed to date, with 4pV > 10^61 erg. North of the supercavity, GMOS has detected warm (T~10^4 K) ionized gas that enshrouds the young stellar superclusters but is redshifted up to + 800 km/s with respect to the southern central galaxy. ALMA detects a similarly redshifted ~10^10 solar mass reservoir of cold (T~10^2 K) molecular gas, but the gas is offset from the young stars by ~1-3 kpc. We propose that the multiphase gas originated from low-entropy gas entrained by the X-ray supercavity, attribute the offset between the young stars and the molecular gas to turbulent intracluster gas motions, and suggest that tidal interactions stimulated the "beads-on-a-string" star formation morphology. Our results illuminate how large-scale AGN feedback and galactic dynamics regulate the localized star formation processes in SDSS J1531+3414, and also offer a potential window into the feedback processes that shaped the earliest galaxy clusters, characterized by similarly dynamic environments.

The Curious Case of Centaurus A

Sachithra Weerasooriya
Carnegie Observatories

The LSST and Roman Space Telescope will bring a groundbreaking era in near-field cosmology within the Local Volume (LV), revealing faint dwarf galaxies with shallow gravitational potentials, which are crucial indicators for studying star formation physics. Recent surveys, including Centaurus A by SCABS and PISCeS observations, explore dwarf satellite systems beyond the Local Group. Employing the semi-analytic model Galacticus, we efficiently simulate Centaurus A's dwarf satellites, a system ten times more massive than the Milky Way, in just 2-3 hours. Our model captures luminosity function trends and luminosity-metallicity relations within the splashback radius. However, models calibrated for star formation physics of the Milky Way satellites do not show any scarcity of dwarfs brighter than -16 mag within 150 kpc, a feature seen in observations. Our models also hint at a quenching phenomenon during cosmic noon, potentially linking AGN-induced quenching to suppressed star formation in Centaurus A's dwarf galaxies.

Which processes can quench star formation in massive, high-redshift galaxies?

Michaela Hirschmann
EPFL

To understand which process(es) can suppress star formation (SF) of massive galaxies as early as z>3 as observed, we present a comprehensive analysis by employing both the GAEA semi-analytic model, the cosmological simulation IllustrisTNG, as well as new cosmological zoom simulations of massive, high-redshift galaxies. Irrespective of the model, we find that AGN feedback is the primary cause of halting SF: Compared to SF, high-redshift galaxies at a given mass, the central BHs of quiescent galaxies have been seeded at earlier times, and have also grown faster. As a result, the quenched galaxies have been exposed for a longer time to AGN feedback. In our cosmological zoom simulations (using the TNG model) of a few massive, high-redshift galaxies, which we ran with and without AGN feedback, we could explicitly show that this physical process is a crucial ingredient for suppressing SF early in cosmic history (without this process, no massive quiescent galaxy can form at all). However, while in IllustrisTNG, the SF suppression in primarily linked to jet-mode feedback, in the GAEA model, this process seems to be mainly attributed to quasar-driven wind feedback. Moreover, we also investigated the role of the large-scale environment and mergers, which we find to only have a minor impact if any at all. Finally, compared to observations, most if not all current model predictions are still below JWST observational measurements of number densities of massive, quiescent galaxies at z>3. This tension is pointing towards fundamental modifications needed for current BH physical models adopted, what will be discussed.

Fast & Furious: ionised winds faster in type-2 than in type-1 AGN at z~2

Giulia Tozzi
Università di Firenze, INAF - Arcetri (Italy)

Although theoretical and numerical studies invoke AGN-driven outflows as crucial ingredients of galaxies' evolution, we still miss definitive observational proof of their real impact on their host galaxies. To shed light on this, spatially resolved observations at the Cosmic Noon (z~2) are fundamental, being this the epoch where AGN feedback is expected to be more effective. In this talk, I will present the latest results on type-2 AGN from SUPER

(Survey for Unveiling the Physics and Effect of Radiative feedback), a completed VLT/SINFONI program which targeted X-ray AGN at z ~ 2 with adaptive optics. We found large evidence of spatially resolved ionised outflows extending on kpc scales, traced via [OIII]λ5007 line emission. If on one hand they seem to be not powerful enough to escape the gravitational potential of their host, thus challenging the ejective feedback mode, on the other they interestingly host faster ionised outflows than their SUPER type-1 counterparts within the same range of bolometric luminosity. I will hence discuss the main implications of this result in the framework of the standard AGN unified picture and evolutionary models of galaxies, showing how the type-2/type-1 dichotomy at high redshift may reflect two distinct life stages of active galaxies more likely than being consequence of projection effects. SUPER has provided new observational clues of the 'blow-out' phase experienced by high-redshift type-2 AGN, where a larger amount of obscuring material favours the acceleration of large-scale outflows via radiation pressure on dust, finally unveiling the central unobscured AGN.

Constraining the Nature of First Galaxies with JWST and ALMA

Maria Emilia De Rossi
Institute for Astronomy and Space Physics (CONICET-UBA), Argentina

By applying a model of primeval dust, we predict the FIR-continuum fluxes of massive galaxies, such as those detected by the JWST at z>7. According to our results, upper FIR flux limits inferred from ALMA observations can constrain dust fractions and gas-phase metallicities in primeval galaxy sources. Encouragingly, when adopting model parameters (e.g. star formation efficiency, gas metallicity, dust-to-metal mass ratio) expected for typical first galaxies, our predicted FIR spectra are in agreement with upper flux limits derived from ALMA. In particular, higher values for the gas metallicity (> 5x10^-2 Zsun) and dust-to-metal ratio (> 0.06) are ruled out by current observations, unless a higher star formation efficiency is assumed. Our findings suggest that ALMA multi-band observations could help to address the chemical composition of dust and its grain size distribution in the early universe. In the future, a crucial challenge would involve not only an improvement of FIR sensitivities, but also extending the wavelength coverage along different ALMA bands.

Extremely Red Quasars and Quasar/Galaxy Evolution

Marie Wingyee Lau
University of California, Riverside

Popular models of galaxy evolution predict that supermassive black holes initially grow in obscurity deep inside dusty galactic starbursts, until they are massive enough to power quasars. Outflows from the quasars that drive major blowouts of gas and dust, which quench star formation and reveal visibly luminous quasars in the galactic nuclei. Dusty quasars might be in a young stage of galaxy evolution with prominent quasar feedback. Our team discovered a population of "extremely red quasars" (ERQs) which are non-radio-selected, intrinsically luminous quasars at cosmic noon selected by their extremely red color from rest-frame UV to mid-IR. ERQs characteristically drive exceptionally fast ionized outflows traced by [OIII]5007 emission, reaching speeds >6000 km s^-1. We obtained adaptive-optics integral-field spectra of ERQs to measure the sizes and spatially-resolved kinematics of the ionized gas. We found evidence that the physical conditions in ERQs are unique and beyond orientation differences from other quasar populations, and the obscuration patterns are global and patchy that are inconsistent with a simple Type II geometry. Currently, we are searching for candidates of even redder, fainter ERQs that may represent a more extreme phase in evolution and/or connect to the more general galaxy population. We are employing DESI imaging surveys and follow up with spectroscopy to confirm these candidates. Upcoming Euclid source catalogs will provide the near IR part of the spectral energy distribution and reduce source confusion in selecting ERQ candidates. Going forward, we will collate spectral databases, polish data analysis tools, and search for signature of quasar feedback and host galaxy feeding via absorption-line spectroscopy which is more sensitive to underdense gas.

Exploring the Relationship Between Early Star Formation and CO in the Dwarf Irregular Galaxy WLM

Haylee Archer
Arizona State University/Lowell Observatory

Dwarf irregular (dIrr) galaxies provide a unique insight into low-metallicity star formation in the local universe. The low-metallicity environments in dIrrs strongly influence the formation of molecular clouds, primarily composed of H2 but detectable through low rotational transitions of CO. Rubio et al. (2015) mapped 10 CO cores, with an additional 35 CO cores mapped by Rubio et al. (in preparation), in the dIrr galaxy WLM, a Local Group dIrr with a metallicity 13% of solar. Archer et al. (2022) explored the environments and star-forming regions surrounding these CO cores revealing no distinct properties driving their formation.

Leveraging JWST's exceptional resolution and sensitivity, we investigate the relationship between the detected CO cores and WLM's young star-forming regions. Analyzing WLM images from the JWST ERS Program #1334, specifically in F090W, F150W, F250M, and F430M filters, we examine the correlation between early star formation and the presence of CO cores. Comparing properties, such as temperature and mass, of young, potentially embedded star clusters near CO cores with those in other areas of the galaxy, we observe that young star clusters near CO have higher masses. Additionally, these star clusters near CO cores overlap with Spitzer 8-μm sources at a higher frequency, suggesting they are at an earlier stage of star formation. However, accurate age estimates of the clusters are needed to confirm these results.

CH+(1-0) in z˜2-6 starburst galaxies: probes of extended reservoirs of multi-phasic turbulent gas

Alba Vidal Garcia
Observatorio Astronómico Nacional

Submillimetre-selected galaxies at redshifts z~2 to 6 are among the most intensely star forming galaxies in the universe. The way they accrete their gas to form stars at such high rates is still a controversial issue. We have detected the CH+(1-0) line in emission and/or in absorption in all the gravitationally lensed starburst galaxies observed so far with ALMA in this redshift range (1,2).

The unique spectroscopic and chemical properties of CH+ allow this transition to highlight the sites of dissipation of mechanical energy. The absorption lines reveal the intermittent dissipation in massive turbulent reservoirs of diffuse molecular gas extending far out of the galaxies(~20kpc). The broad emission lines with widths up to a few thousands of km/s, arise in myriad molecular shocks powered by the feedback of star formation (3,4,5) and, in one case, an active galactic nucleus (6).

The CH+(1-0) lines therefore probe the sites of prodigious energy releases in the CGM of these starburst galaxies. Mechanical energy is stored in turbulent motions of molecular gas before being radiated away and lost. These turbulent reservoirs therefore act as extended buffers of mass and energy over timescales of a few tens to 100Myr.

In comparison, the CH+(1-0) line observed in one nearby starburst galaxy with Herschel/HIFI suggests that the turbulent luminosity of the CGM increases faster than the SFR as z increases, a possible signature of the increased importance of gravitational infall infeeding the CGM turbulence at higher z.

(1) Falgarone et al. 2017 (2) Vidal-Garcıa et al. In prep (3) Godard et al. 2019 (4) Lehmann et al. 2020 (5) Lehmann et al. 2021 (6) Vidal-Garcıa et al. 2021 (7) Li et al. 2019 (8) Frayer et al. 2018

First-of-its-kind detection of diffuse HI emission in the CGM of local galaxies

Sanskriti Das
KIPAC, Stanford University

The circumgalactic HI might hold the clue to the missing accretion: the mismatch between the HI accretion rate and star formation rate of local (z~0) galaxies. If it traces the neutral fraction of a predominantly ionized CGM, it could also host missing galactic baryons. Using the Green Bank Telescope, we probed the 21-cm emission from HI in the CGM of several local galaxies out to 100 kpc impact parameter at an unprecedented sensitivity of 10^16 cm^-2. We detected HI of diverse spectral shapes, velocity widths, and column densities. Interferometric maps from the Westerbork Synthesis Radio Telescope cannot explain >50% of these single-dish detections. This excess circumgalactic HI along major axes pointings co-rotates with the HI disks and is an inflow/fountain along the minor axes pointings. Whether it accounts for the missing baryons and missing accretion is subject to individual targets.

Spatially resolved star formation in galaxies across cosmic time

Abdurro'uf Abdurro'uf
The Johns Hopkins University

We study the spatially resolved stellar populations of 444 galaxies at 0.3 < z < 6.0, combining imaging data from the HST and JWST to perform spatially resolved SED modeling using piXedfit. The high spatial resolution of the imaging data combined with magnification from gravitational lensing in the cluster fields allows us to resolve a large fraction of our galaxies to sub-kiloparsec scales. At redshifts around cosmic noon and higher ($2.5 \lesssim z \lesssim 6.0$), we find mass-doubling times to be independent of radius, inferred from flat specific star formation rate (sSFR) radial profiles and similarities between the half-mass and half-SFR radii. At lower redshifts ($1.5 \lesssim z \lesssim 2.5$), a significant fraction of our star-forming galaxies shows evidence for nuclear starbursts, inferred from a centrally elevated sSFR and a much smaller half-SFR radius compared to the half-mass radius. At later epochs, we find more galaxies suppress star formation in their centers but are still actively forming stars in the disk. Overall, these trends point toward a picture of inside-out galaxy growth consistent with theoretical models and simulations. We also observe a tight relationship between the central mass surface density and global stellar mass with ~0.38 dex scatter. Our analysis demonstrates the potential of spatially resolved SED analysis with JWST data. Future analysis with larger samples, including in the local universe using data from Euclid and LSST, will be able to explore further the assembly of galaxy mass and the growth of their structures.

Understanding the Star Formation Rate and the Effect of Protostellar Feedback at the Cloud-scale

Sabrina Appel
Rutgers, the State University of New Jersey

Gravity, turbulence, magnetic fields, and stellar feedback all play important roles in star formation. The impact of these physical processes is reflected in the distribution and dynamics of the gas in star forming regions. Understanding the impact of each of these processes on the gas is important for understanding both observations and simulations of star formation. In this talk, I investigate the connection between cloud-scale processes and the gas distribution and dynamics using 3D magnetohydrodynamical simulations of star-forming regions. First, we investigate how the density probability distribution function (PDF) changes with the inclusion of gravity, turbulence, magnetic fields, and protostellar outflows. We find that self-gravity produces a power-law tail at high densities and the inclusion of feedback from protostellar outflows produces time-varying deviations from a lognormal distribution at the low densities. We also explore how the gas dynamics varies with the inclusion of various physical processes and compare the gas dynamics to the features of the density PDF. We find that protostellar feedback produces rapidly expanding and compressing gas at low densities. Finally, we compare the gas dynamics as a function of density to the star formation rate.

Links between Star Formation and Orbital History in Local Group Dwarfs

Paul Bennet
STScI

Star formation in dwarf galaxies is a key component to understand star formation as a whole. These smaller galaxies give insight both into how the larger galaxies assemble while also acting as small scale laboratories for a number of physical processes. In general our current understanding is that dwarf galaxies are star forming in the field and quench as they approach massive hosts which strip them of the gas reservoirs needed for star formation. However recent results from the Local Volume, such as the SAGA survey, have shown that our current understanding might be over quenching dwarf galaxies, with many Milky Way analog galaxies having dwarf satellites that are more star forming than those seen in the Local Group (LG) or in cosmological simulations. I will present new proper motions obtained from HST for a sample of distant dwarf galaxies in the LG, significantly expanding both the number of systems for which we have full position-velocity information and crucially looking at more distant dwarfs than previous samples, including distant quenched dwarf galaxies. This 6D position-velocity information can be used to calculate the implied orbits. I will discuss how this information allows new science with the LG dwarfs and their hosts, linking the star formation and orbital histories of dwarfs to determine when specific dwarfs quenched and what relation this might have to the massive galaxies of the LG, or if these dwarfs quenched through entirely internal feedback.

Underluminous dwarf galaxies challenge the radio and X-ray SFR-Luminosity relations

Abhijeet Borkar
Astronomical Institute of the Czech Academy of Sciences

Star formation rates (SFRs) of galaxies are often estimated from their observed luminosity. These SFR-luminosity relations were established for local "normal" galaxies (stellar mass > 10^10 Msun). Do they still work for highly star-forming low-mass galaxies present in the Early Universe? Recently launched and next generation of observatories will be able to probe lower mass galaxies at very high redshifts. Thus, it is crucial to understand how the luminosity-SFR relations hold for the low-mass galaxies with a diverse range of SFRs and cosmic ages. In this work, we explore the link between the radio luminosity and the star formation rate, and how it varies across different types of galaxies.

Green Peas (GPs; z~0.4) and Blueberries (BBs; z~0.05) are highly star-forming dwarf galaxies (Mstar <10^9.5 Msun), which are considered local analogs of the early galaxies responsible for the reionization of the Universe. We analysed new and archival radio and X-ray data for a large sample of GPs and BBs. We find that only a small fraction of GPs and BBs are detected, although about 75% of sources could be detected, and the detected sources are often underluminous. Our work suggests that towards the lower end of the galaxy mass and SFR, the radio and X-ray flux-to-SFR relation deviates away from the relations established for larger galaxies, and typical compact, highly star-forming dwarf galaxies, such as GPs and BBs, are markedly underluminous.

The Star Formation in Radio Survey: 3 – 90 GHz Photometry and Imaging of Nearby Star Formation

Anna Dignan
National Radio Astronomy Observatory

Observations taken at radio frequencies allow us to determine the rates of massive star formation in nearby extragalactic regions. Specifically, multifrequency radio data can be used to separate nonthermal from thermal free-free emission in HII regions. This thermal emission comes from gas ionized by forming stars, making thermal emission a direct, dust-free tracer of massive star formation. We present 3, 15, 33, and new 90 GHz imaging and photometry of 63 star forming regions in 22 nearby galaxies using data collected by both the

Green Bank Telescope (GBT) and the Very Large Array (VLA) as part of the Star Formation in Radio Survey (SFRS). We use the results of this imaging and photometry to decompose the radio spectra and determine the importance of including 90 GHz emission to accurately determine star formation rates at cm and mm wavelengths.

Effect of diffuse background on Schmidt relation in nearby star-forming galaxies

Nimisha Kumari
Space Telescope Science Institute

The Kennicutt-Schmidt relation relating the surface densities of the star-formation rate (SFR) and gas (atomic and molecular) is a widely accepted star-formation relation. However, it is a disk-averaged law smoothing over local variations and hence may not provide an explanation for the local relationship between SFR and gas density at the sub-galactic scale. Various groups have conducted spatially-resolved studies of star formation in nearby spiral galaxies using different methods to probe this further. However, most of these studies do not take into account the effect of the spatially varying diffuse background, which is potentially present in all star-forming galaxies and affects all the usual SFR tracers (optical, far-ultraviolet, and mid-infrared). In this contribution, I present the results from an analysis (Kumari et al. 2020) of nearby spiral galaxies using aperture photometry, where the effect of the diffuse background is taken into account. Making use of a novel split of the overall light distribution as a function of spatial scale allows us to subtract the diffuse background in the SFR tracers and determine the current localized SFR density. This is then combined with the gas density estimates (molecular gas from CO(2-1) and atomic gas from HI) to study the relation between SFR and gas density. An analysis is also done for the effect of diffuse background in the atomic gas, should it be present. This work indicates that removal of a diffuse background in SFR and atomic gas tracers results in a slope $\sim 1.4 \pm 0.1$, which agrees with dynamical models of star formation accounting for flaring effects in the outer regions of galaxies.

Does star formation drive increased molecular gas turbulence in galaxy centres?

Jennifer Laing
McMaster University

Galactic bars play an important role in the dynamical evolution of their host galaxy, but their own evolution and impact on the local gas reservoir and star formation rate are still open questions. Recent work by the Physics at High Angular resolution in Nearby GalaxieS (PHANGS) collaboration found higher molecular gas surface densities and velocity dispersions in barred galaxies compared to unbarred galaxies. The higher turbulence found in bars is expected to create the observed increases. In this work, I explore bar turbulence in molecular gas using published high resolution ($\sim$100 pc) measurements of CO(2-1) from the PHANGS-ALMA survey. I compare properties of the molecular gas, such as surface density, velocity dispersion and star formation rate, in the centres of barred and unbarred galaxies. All three quantities are found to be enhanced in barred galaxy centres.

Milky Way Marvels: Young Massive Clusters and Associations from the Latte Suite of FIRE Simulations

Davoud Masoumi
University of California, Merced

Star clusters and associations offer crucial insights into stellar evolution, the role of feedback on galactic dynamics, and the intricacies of star and planetary system formation. Recent advancements, driven by the Gaia mission, have significantly expanded our knowledge of stellar groups within the Milky Way. Gaia's precision in proper motion and parallax measurements, especially in the latest Gaia DR3 release, has refined our understanding of cluster properties. This progress aligns with a pivotal phase in near-field studies like PHANGS-HST and PHANGS-JWST which coincides with advancements in galaxy zoom-in simulations that offer a cosmological framework to study stellar groups and Giant Molecular Clouds. We leverage the Latte suite of FIRE-2 simulations to explore the fundamental properties of young massive stellar groups, both bound and unbound, at redshifts $z < 0.008$, focusing on those younger than 3 Myr at identification and more massive than ~10^4.5 M⊙. Our analysis covers boundedness, mass, size, 1D velocity dispersion, and metallicity [Fe/H] spread. We identify these stellar groups by utilizing a Friends-of-Friends algorithm and track them in snapshots with ~ 1Myr timesteps, enabling a detailed examination of their dynamical and chemical evolution. Our analysis focuses on star clusters younger than 3 Myr, predating supernova feedback, providing insights into the small-scale measurable imprints of the early stages of stellar feedback processes. We discuss the implications of our findings, draw comparisons with observational results, and evaluate the Latte simulations' capability to replicate realistic star clusters and associations.

UVCANDELS: Are differences in the UV and optical sizes of galaxies driven by dust or star formation?

Kalina Nedkova
Johns Hopkins University

The build up of stars in galaxies is believed to occur through inside-out growth, whereby galaxies grow their central regions first and their outskirts later on. This is supported by measurements of larger galaxy sizes in the rest-frame UV than optical, as the UV traces recent star-formation while the optical is sensitive to the older underlying stellar population. However, dust complicates the interpretation of such observations. We present rest-frame UV and optical galaxy sizes at $0.5 \leq z \leq 3.0$ measured from high resolution UVCANDELS imaging that allows these comparisons to be made over a larger redshift range than previously possible. Our results show that massive disk galaxies (>10^10 Msun) are typically much larger in the UV, which is consistent with the literature. To understand if this difference is driven by dust or inside-out growth, we perform an analysis of mock disk galaxies from the VELA simulations in the same multi-wavelength fashion as the observations. We find that when dust is included, the simulations reproduce observations. However, once dust is accounted for, the difference between the rest-frame UV and optical sizes of disk galaxies is consistent with zero. Since dust alone can account for differences between the rest-frame UV and optical sizes of star-forming galaxies, we find that variations in galaxy size with wavelength do not constitute evidence for specific galaxy growth scenarios.

The Arp 240 Galaxy Merger: A Detailed Look at the molecular Kennicutt-Schmidt Law on Sub-kpc Scales

Alejandro Saravia
University of Virginia

The Kennicutt-Schmidt (K-S) Law has been fundamental in understanding star formation (SF) in galaxies across all redshifts. However, recent observations at sub-kpc scales in nearby galaxies have revealed significant deviations from this standard law. In my presentation, I will discuss results from a case study on the early-stage luminous infrared galaxy merger, Arp 240 (NGC 5257-8). Utilizing VLA radio continuum and ALMA observations of molecular gas, combined with a uniform grid analysis, we estimate the star formation rates (SFR) and molecular gas mass surface densities across 341 regions across the merger, at physical scales of ~500 pc. We found that although the SFR generally remains proportional to the molecular gas surface density in Arp 240, we observe a significantly shallower K-S Law slope. Furthermore, distinct slopes across different morphological features within the galaxies are identified, with the highest surface brightness components exhibiting the steepest slopes. This suggests that localized conditions influence star formation efficiency, thereby affecting the correlation between SFR and molecular gas. Additionally, we detect spatial decoupling between SFR and molecular gas tracers in NGC 5257, which impacts their correlation. Lower-resolution or integrated measurements can mask these local conditions and decoupling effects, leading to larger regions adhering more closely to the established K-S Law.

Filamentary structure and mid-IR SED variation in PHANGS-JWST disk galaxies as a feedback barometer

David Thilker
Johns Hopkins University

We utilize PHANGS-JWST imaging to quantify the effects of feedback in 19 nearby spiral galaxies. MIRI observations reveal the dusty ISM to be highly structured in the form of filaments and bubbles, with visual evidence for a changing MIR spectral distribution as a function of environment (e.g. near star-forming complexes versus in quiescent regions). Utilizing Constrained Diffusion Decomposition we transform each galaxy into a set of flux-conserving multi-scale images for each observed wavelength (F770W, F1000W, F1130W, and F2100W). These images are then further processed to identify significant filamentary structures that together constitute the dust filament network (DFN). We present the measured properties of the DFN, focusing on quantities such as filament length, aspect ratio, and estimated dust mass; and explore metrics for morphologically distinguishing between zones of quiescence, dynamical structuring, and mechanical feedback domination. Observed quantities are compared to equivalent measures from simulated galaxy disks. In order to constrain radiative feedback, we utilize the decomposed multi-band images directly to measure the change in MIR intensity and SED shape versus scale and location across our galaxy sample.

Radiation Pressure as a Feedback Mechanism in Local Galaxies

Ian Blackstone
Ohio State University

Radiation pressure on dust is an important feedback process around star clusters and may eject gas from bright sub-regions in star-forming galaxies. Studies of individual star clusters suggest radiation pressure may dominate other feedback mechanisms. In this talk I will discuss the physics of radiation pressure and the conditions needed for radiation pressure to be dynamically important within a star-forming sub-region. I will then present an analysis of thousands of sub-regions across two local star-forming galaxies, NGC 6946 and NGC 5194, with estimates of the radiation pressure force and the Eddington ratio within those regions. I show how uncertainties about the cloud size and the cluster age are important factors in determining if regions are super-Eddington. Depending on the assumed height of the dusty gas and the age of the stellar population, we find that up to ~10 percent of the sightlines are super-Eddington and that these regions may be accelerated to 5 - 15 km/s by radiation pressure alone.

Gas Retention in Young Super Star Clusters

Liang Dai
University of California, Berkeley

Can super star clusters retain gas expelled by the massive stars and chemically enrich itself in the first 10 Myr of evolution? The simple picture has been that stellar winds and supernova explosions evacuate any dense gas and drive a hot, dilute cluster wind. However, it has been theoretically suggested that for a sufficiently compact star cluster the hot cluster wind fails to develop due to gas condensation via rapid radiative cooling. The star cluster therefore retains gas with altered element abundances which could be the origin of multiple stellar populations. Through nebular spectroscopy, we present observational evidence that some young super star clusters in the distant universe retain in the gravitational potential condensed massive star ejecta. The observed nebular spectrum can be explained by a hydrodynamic model that describes gas in a state of supersonic turbulence driven by supernova explosions, yet the supernova feedback in the highly radiative regime is not efficient enough to eject the gas.

H II region candidates in M94 with SIGNALS

Emma Jarvis
David A. Dunlap Department of Astronomy & Astrophysics at the University of Toronto

The study of ionized gas regions provides important information on star formation mechanisms, stellar feedback and, more globally, galaxy evolution. By studying large ensembles of these regions we can learn about the role of the local environment on the star formation process. We present observations of M94 from The Star formation, Ionized Gas, and Nebular Abundances Legacy Survey (SIGNALS); the largest and most detailed spectroscopic study of star-forming region properties in different galactic environments. We use data cubes from the imaging Fourier transform spectrometer SITELLE which has a high spatial resolution (0.8”) and large field of view (11’x11’). With these data cubes, we perform corrections to the observed data by subtracting the stellar population contribution and the sky contribution before extracting the corrected fluxes of observed emission lines (including Hα, Hβ, O[III] and N[II]). We then use a technique adapted to imaging spectroscopy to identify and extract parameters from H II region candidates found in M94. This enables the extraction of the position, velocity, luminosity, size, dust extinction, and the emission-line fluxes and line ratios for individual spaxels as well as the integrated spectrum for each region. All of these parameters are compiled in a new HII region catalog ideal to study variations in the HII regions characteristics over their environment.

Star-formation Hierarchy and Multi-scale Stellar Associations in the 38 PHANGS-HST Galaxies

Kirsten Larson
STScI

We developed a method to identify and determine the physical properties of stellar associations using Hubble Space Telescope (HST) NUV-U-B-V-I imaging of nearby galaxies from the PHANGS-HST survey. We have now expanded our initial study to the full sample of 38 PHANGS-HST galaxies. We estimate the stellar associations' age and mass distributions using color-color diagrams and SED fitting and compare to results found with compact clusters. This method is ideal for identifying young star-forming regions and provides a more complete census of the recent star formation activity than found with previous cluster and compact association catalogues. With our multi-scale hierarchical stellar associations, we can trace the sizes and structures of star formation across different galaxy dynamics (bars, spiral arms, and flocculent structures) to investigate the affects of galaxy dynamics on star formation growth. This sample of multi-scale stellar associations provides a census of recent star forming structures as traced by their stellar positions in the PHANGS-HST galaxies and provides a resource for further comparisons to other data sets of star formation studies using CO gas and HII regions.

The Youngest, Highly Obscured, Radio Quasars and the Impact of Their Small Powerful Jets

Carol Lonsdale
NRAO Charlottesville

The WISE Ultra-Red Radio Quasars are the reddest known radio-loud systems in the restframe ~0.7-5um, found to host heavily obscured young jetted quasars at redshifts 0.5-3.5, as well as starbursts, based on ALMA, VLA and optical campaigns (Lonsdale et al. 2015; Patil et al. 2020, 2022). They resemble "naked tori" in the mid-IR, due to the dominance of the powerful obscured nucleus over the entire host galaxy light. The powerful jets are found to be small and young, ~50pc to a few kpc in scale. The VLBA data are presented at this meeting by Colin Lonsdale, while pilot ALMA continuum and line imaging results for two sources are presented by Pallavi Patil. In this contribution I summarize our results to date, and describe our current understanding of the sample in terms of a short critical stage of merger-driven obscured starburst and super-massive black hole (SMBH) growth, during the most compact (short) phase of mass infall prior to a blowout, likely leading to feedback into the most central dense ISM. I will also describe new work aimed at clarifying the space densities of these short but powerful events, and the event lifetimes, and hence the overall role of this phenomenon in galaxy evolution.

Star formation efficiency observation results of 6 galaxy bulges with <100 pc resolution

Anan Lu
McGill University

Star formation efficiency has been shown to vary across different environments, particularly within galactic starbursts and deep within the bulges of galaxies. The bulges of galaxies share similar environments with elliptical galaxies, with rich molecular gas reservoirs but scarce star formation (SF). With the capabilities of ALMA, we can now spatially resolve the fundamental SF units, giant molecular clouds (GMCs, with size of ~10 pc), in bulges and elliptical galaxies up to ~80 Mpc away. We also measure the spatially resolved star formation rate at comparable resolution, using SITELLE at CFHT. In this talk, I will present a sample of 6 elliptical or bulge-dominated galaxies, which are observed with ALMA and SITELLE and reveal suppressed SF. I will offer two detailed case studies: (1) We find that within the central kpc of NGC 3169, the molecular gas surface densities and depletion times increase with decreasing radius, as a result of AGN feedback and bulge morphology (Lu et al. 2022). (2) In NGC 524 we measure a similar radial profile but with strong shear forces that lead to diffuse ionized gas and GMCs with low surface brightness and high virial parameters (Lu et al., submitted). I will place these results in the context of the larger sample and discuss the spatially-resolved star formation efficiencies of these galaxies, their radial profiles, as well as the lifecycle and properties of GMCs and HII regions that regulate their SF.

Probing the baryonic evolution in the early growth phase of the Universe with the ALPINE survey

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The early growth phase of the Universe ($4 < z < 6$) marks a pivotal transition between the primordial galactic formation and the onset of the peak of cosmic star formation rate density. During this phase, galaxies are rapidly growing in mass and size, fueled by the intricate interplay of gas and dust within the interstellar medium (ISM). Constraining the evolution of these galaxies is a challenge owing to degeneracies in cosmological simulations and chemical evolution models.

In this work, we characterize the sample of main-sequence star-forming galaxies observed by the ALMA Large Program (ALPINE), to probe baryonic evolution. We constrain the models using observations for metallicity and molecular gas masses. The models take into account various parameters like specific gas mass (ratio of gas mass to stellar mass), mass loading factor (outflow efficiency of the gas) and inflow parameter to accurately reproduce the observations obtained from the fitting of spectral energy distributions of these galaxies. Additionally, we test the hypothesis for the Top - Heavy Initial Mass Function (IMF) compared to Chabrier IMF in order to reproduce higher observed values of specific dust mass and specific star formation rate. We found that the observed gas masses of these galaxies can be explained by employing the models with mass-loading factor ≥ 1, with a smaller subset of this sample being probed by a top-heavy IMF. These results provide insights into the evolution of gas and dust in these galaxies, highlighting the crucial role of chemical evolutionary models in understanding galactic evolution.

Studying HII regions population using synthetic population made with TODDLERS for the SIGNALS progra

Sebastien Vicens
Laval University

Studying HII regions as a population through various diagnostics, like their luminosity function (LF), size function, and BPT diagrams (based on emission line ratios), gives an insight on the galaxy star formation on a global level. For example, the bright end of the LF can be described as a power law with a turnover point at lower luminosity, but these parameters seem to change from one galaxy to another.

With the new HII regions emission library TODDLERS (Time evolution of Observables including Dust Diagnostics and Line Emission from Regions containing young Stars), synthetic HII region populations are calculated. We use these models to study how global and local parameters, such as the star formation rate and efficiency, the metallicity, or the birth cloud density, can impact the shape and boundaries of the HII region LF, the HII region size distribution, and BPT diagrams. Using synthetic populations, we assess the uncertainties related to the different methods used to analyze these diagnostics. Among these methods for the LF, simple fits to a binned LF with constant-sized luminosity or with fixed number of HII regions per bin, or maximum likelihood method are considered.

We then compare our models with HII regions diagnostics of galaxies observed with SITELLE as part of the SIGNALS program in order to discuss the effect of global and local parameters of star formation in those galaxies.

The Effect of Outflows on the Ability to Accurately Age-Date Star Clusters in PHANGS Galaxies

Brad Whitmore
Space Telescope Science Institute

Feedback caused by the outflow of gas from young star clusters is a critical component of the regulation of the star formation rate in galaxies, and for slowing the overall consumption rate of gas in the universe. However, a secondary, generally unappreciated result of this feedback is the effect it has on our ability to accurately age-date star clusters, and hence to fully understand the evolution and interplay between the clusters, the gas and dust, and the formation of new stars and star clusters. Currently, most SED modeling codes that incorporate IR emission (e.g., Draine models) are designed for integrated populations, and assume energy balance to compute re-emission in the IR from the dust reddening of starlight. The problem is much different for the modeling of young star clusters because the dust emission and heating sources do not appear in the same aperture due to outflows that remove the gas and dust from their central regions in only a few million years. As part of this effort, we present a set of empirical HST+JWST SED templates for star clusters for a range of ages which have been inferred through a number of different methods. A key result is the finding that essentially all star clusters with strong PAH emission have ages of 5 My or younger.

Authors: Brad Whitmore, Rupali Chandar, Janice Lee, Jimena Rodriguez, David Thilker, and the Phangs Team

Spectral synthesis models for young stellar populations including binary stars

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We have developed the GALSEVN set of spectral evolution models designed to study young stellar populations by combining the SEVN population-synthesis code, which includes binary-star processes, and the GALAXEV code for the spectral evolution of stellar populations. From the new models we can predict the evolution in time of VMS and WR stars including stars formed through mass exchange in binary systems. The star formation history of stellar systems derived with the GALSEVN models will differ from that derived using the standard GALAXEV SSP models due to the appearance of new VMS and WR stars through binary interactions. An instantaneous burst of star formation will look as a burst of finite length, lasting a few Myr. This must be taken into account when determining the SFH of very young stellar systems in the early universe. An application of these models has been published in Lecroq et al. (2024, MNRAS, 527-3, 9480).

JWST/NIRSpec spectroscopic detection of a BL AGN within a dusty star-forming galaxy

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Submillimeter galaxies (SMGs) are an infrared-detected galaxy population with large amounts of dust, which attenuates the rest-frame UV and optical emission from young stars then thermally reemits it in the IR. Only the brightest galaxies have been studied from ground-based telescopes, finding ~20% of them have AGN features. However, ground based spectroscopic observations of fainter SMGs are challenging due to high obscuration. Faint SMGs were detected ($S_{850\mu\rm m}\leq 6~\rm mJy$) in the SCUBA-2 Cosmology Legacy Survey (S2CLS) carried out in Extended Groth Strip (EGS) deep field. This field has been extensively observed, allowing multi-wavelength analysis of SMG physical and morphological properties. The Cosmic Evolution Early Release Science Survey (CEERS) observed EGS with JWST, obtaining imaging data with NIRCam and MIRI and spectroscopy with NIRSpec. Some of CEERS' pointings coincide with the deepest area observed by S2CLS, and also acquired NIR spectra of a typical faint SMGs (S2CLS-EGS-850.021) with robust optical counterparts. We identified multiple emission lines, as well as the Ca triplet. We classify 850.021 as an AGN in the BPT diagram, confirmed by a broad line component in the recombination lines. However, in photometric SED fits, we found only ~8% contribution of the AGN to the galaxy emission. The multi-wavelength morphology analysis shows a disk component, with a non-classical bulge, consistent with an obscured AGN. AGNs detection within SMGs and understanding their impact on the star-formation of the system is relevant understand the AGN contribution in dusty star-forming galaxies and their impact on the global star-formation.

Correlation Between Ionization Parameter and Oxygen Abundance Depends on the Model!

Ray Garner
Texas A&M University

The variations of oxygen abundance and ionization parameter in HII regions are usually thought to be the dominant factors that produce the variations seen in observed emission line spectra. However, if and how these two quantities are physically related is hotly debated in the literature. We present ongoing research into the correlation between abundance and ionization parameter using the Star formation, Ionized Gas, and Nebular Abundances Legacy Survey's (SIGNALS) large sample of Local Universe HII regions collected with the CFHT imaging spectrograph SITELLE. Using a combination of this large observational data set and photoionization models, we show that the correlation (if any) between ionization parameter and oxygen abundance is highly model dependent.

Exploring extended X-ray emission opposing the radio jet axis in quasars 3CR 14 and 3CR 34

Tom Higginson
University of Bristol

Jets from Active Galactic Nuclei have long been observed to interact with the interstellar medium triggering or quenching star formation via feedback. Interactions with the surrounding material can cause various structures, from compact jet knots to large sweeping filaments. 3CR 14 (z=1.469) has been observed by Chandra to have a significant X-ray emission to the east of the core which is not observed in radio, infrared, optical and UV emission. We suggest this X-ray emission, perpendicular to the jet axis, is due to hot X-ray gas, once displaced by a young jet, now contracting back towards the core as jet density decreases. 3CR 34 (z=0.69) has X-ray emission north and south of the core, perpendicular to its east-west jet axis. However, unlike 3CR 14, 3CR 34 has clear radio emission to match the X-ray extension. A bright radio filament near the core that appears as a bow shock flowing into large wings to create an X-shaped structure. Studying the X-ray and optical emission within the bow shock could provide an insight into star formation triggered by jet shocks passing through IGM/ICM clouds in 3CR 34.

Looking at the AGN Impact on the ISM in Simulated and Observed Galaxies Near and Far

Pallavi Patil
Johns Hopkins University

The merger-driven evolutionary scenario predicts the presence of a critical transitional phase during which the recently (re)ignited Supermassive Black Hole (SMBH) is fueling at its peak and is actively injecting kinetic energy into the host’s Interstellar Medium (ISM). This SMBH growth occurs behind thick columns of dust while the host galaxy is still experiencing substantial starburst activity. Although there is mounting observational evidence of AGN-driven impact on the ISM, we still do not understand how the AGN can regulate the galaxy growth by driving outflows and quenching the SF. In this talk, I will present a comparison of SOFIA FIFI-LS and Herschel PACS observations of heterogeneous samples of nearby galaxies with the prediction of key ISM tracers such as [CII], CO, and H2 estimated in simulated galaxies from SIMBA cosmological simulations. The modeling performed using Powderday and Slick allows us to look across a wide range of parameters, e.g., AGN fraction, obscuration, warm gas temperature, dust properties, and merger state. We extend our characterization of the ISM and dust to a distant population of heavily obscured quasars (z~1-3) selected by cross-matching WISE-NVSS surveys (sample presented by Carol Lonsdale). Pilot ALMA investigations of cosmic noon quasars show the dust and cold molecular gas distribution in this unique sample that is likely to be in the post-merger state. Finally, I discuss the implications of such comparison studies that would be beneficial for understanding the impact of AGN on their host galaxy over a significant range of cosmic time.

The H II Regions of the SIGNALS' galaxy NGC 4395

Mykola Posternak
Université Laval

Generations of stars with changing properties shape the appearance of galaxies and mark the passage of time with clues about the different mechanism influencing star formation and galaxy evolution. A detailed study of HII regions, the ionized gas surrounding young star forming regions, is thus a key component for understanding galaxies. NGC 4395 was observed with SITELLE, the imaging Fourier transform spectrograph (IFTS) at the Canada-France-Hawaii Telescope, as part of SIGNALS. This survey aims to investigate over 50 000 spectroscopically and spatially resolved H II regions in approximately 40 nearby star-forming galaxies, enabling a detailed study of the small-scale physics of star-forming regions. Located at a distance of 4.3 Mpc, NGC 4395 is an isolated nearby dwarf galaxy which hosts a Sy1 type AGN with multiple star forming regions in asymmetric spiral arms. The impact of the stellar populations, gas chemical and dynamical state, and central black hole activity of NGC 4395 on its history has not yet been studied in detail. We present here preliminary results for the HII regions of NGC 4395. Using the strong emission lines seen in the visible with SITELLE, more than 1000 HII regions are detected over the whole galaxy disk. An emphasis is put on the emission regions' detection code optimized for SIGNALS/SITELLE galaxies. BPT diagnostic diagrams and the gas kinematic and metallicity gradient are shown for NGC 4395. This analysis will help us to better understand the mechanisms responsible for the galaxy asymmetric morphology and its star formation history.

Near-IR Observations of Post-Starburst Galaxies in The Local Universe

Akshat Tripathi
University of Illinois at Urbana Champaign

Post-starburst galaxies (PSBs) represent a critical phase in galaxy evolution. Despite their rarity in the local universe, ~40% of all galaxies are believed to have gone through a post-starburst phase. These transitioning galaxies have undergone a burst of star-formation, followed by rapid cessation resulting in little current star-formation. Despite low star-formation rates (SFRs), a majority of them host significant amounts of cold molecular gas that should, theoretically, be forming stars. Many studies have attempted to understand the cause of low star-formation efficiency (SFE) in PSBs, however, they are often limited by the effects of dust attenuation that can only be probed at longer wavelengths. In this work, we present, for the first time, near-IR observations from FIRE/Magellan of a large sample (50) of PSBs. We find that a majority (14/50) of the galaxies whose nature can be constrained via our near-IR diagnostic diagram are dominated by either AGN or LINER-like emission, consistent with previous results conducted in the optical. In addition, we discover the presence of AGN emission in 3 galaxies that were likely previously missed by optical studies due to excess dust extinction. We further investigate the source of gas excitation by making use of various ro-vibrational transitions of the Hydrogen molecule, finding that a variety of sources are at play in PSBs that dominate gas emission such as UV, X-rays and shocks. Finally, we also make use of various Pa-α and Br-γ SF tracers to determine the cause of lower SFEs in PSBs.

L-Galaxies: Debugging galaxy evolution across cosmic epochs through galaxy scaling relations

Akash Vani
Max Planck Institute for Astrophysics

L-Galaxies is a semi-analytical galaxy formation model that employs a suit of physical prescriptions to model baryonic physics on top of dark matter halo merger trees from the Millenium-I & -II simulations. This study presents an extensive comparison between the L-Galaxies simulation and several observations from different fields, including CANDELS, COSMOS, JADES, and CEERS, complimented by imaging data from SDSS, JWST, HST, and Spitzer observatories. Our investigation spans across a large redshift range ($0 \lesssim z \lesssim 10$) and a broad mass spectrum ($7 \lesssim \log(M*/M\odot) \lesssim 12$).

In particular, we examine the three most recent versions of L-Galaxies (Henriques+15,20, Ayromlou+21), which include resolved galaxy properties and were independently calibrated using an MCMC approach based on low redshift ($z \lesssim 2$) observations of the stellar mass function and the quiescent galaxy fraction. In this work, we study the redshift evolution of different galaxy scaling relations provided by different recent publications, including the main sequence of star-forming galaxies, galaxy stellar mass function, mass-size relation, central surface mass density relation, mass metallicity relation, molecular gas mass fraction and the cosmic star formation rate density. These relations are examined for both star-forming galaxies (SFGs) and quenched galaxies (QGs).

Our analysis shows that the majority of the simulation predictions are in qualitative agreement up to $z \sim 2$. However, several tensions persist at both low and high redshift, underscoring the need for future refinements in the physical prescriptions of L-Galaxies. These tensions include a low number QGs, beginning at $z \sim 1$ and reaching a factor of 3 dex by $z \sim 3$. Conversely, a more robust suppression of star formation for massive, low-redshift galaxies is required, underscoring the necessity for improved quenching mechanisms, particularly AGN feedback at high redshifts. Using galaxy scaling relations, we also probe other aspects of AGN and stellar feedback along with chemical evolution in the model's framework. Lastly, we discuss the possibility of recalibrating the model for greater coherence with high redshift observations.

VODKA-JWST: A 3.8 kpc dual quasar at cosmic noon in a powerful starburst galaxy

Yu-Ching Chen
Johns Hopkins University

Studying the interaction between kilo-parsec (kpc) dual quasars and their host galaxies via spatially resolved Mid-Infrared (MIR) spectra was challenging before the arrival of JWST. In this talk, I will present JWST MIR observations of J074922.96+225511.7, a dual quasar with a projected separation of 3.8 kpc at the redshift of 2.17. We detect spatially extended [Fe II] 5.34μm and PAH 3.3 μm emissions and derive the SFR of 10^3 solar mass/year for J0749+2255 using PAH 3.3μm, consistent with those in typical star-forming galaxies at z ∼ 2. We do not observe any quasar-driven outflow that impacts PAH and [Fe II] in the host galaxies. Based on the expected value from star formation, the [Fe II] 5.34μm line likely originated from the star-forming regions in the host galaxies. Our study showcases the capability of JWST to conduct spatially resolved MIR observations for kpc dual quasars at z ∼ 2, enabling an examination of their relationship with the host galaxies.

Star Formation and AGN Activity Disentangled: SITELLE Instrument's Role in NGC 4258 a Seyfert Galaxy

David Fernandez-Arenas
Canada-France-Hawaii Telescope

In estimating the Star Formation Rate (SFR), the Hα luminosity of HII regions has been a traditional metric. However, caution is needed as Hα can also be excited by active galactic nucleus (AGN) radiation fields, making it an unreliable diagnostic for SFR in AGN narrow line regions (NLRs). In contrast, [O III]λ5007 luminosity correlates directly with the AGN ionizing radiation field within AGN-dominated regions but is not a valid diagnostic in areas with active star formation. Global colours analysis and integrated SFR provide limited insight into the physical processes impacting the gas reservoirs within AGN host galaxies. Therefore, it is crucial to separate the composite spectra of Seyfert galaxies into contributions from both star formation and AGN activity before calculating SFRs or AGN luminosities for a better interpretation of the chemo-dynamical processes in the ISM. To address these challenges, we leverage the potential of SITELLE data, conducting large field-of-view mapping encompassing not only central regions but also the outskirts of local galaxies. This dataset enables an in-depth investigation of spatial distribution properties of the ionized ISM at scales of 20 pc within the framework of SIGNALS, the Star Formation, Ionized Gas, and Nebular Abundances Legacy Survey at CFHT. This allows for spatial and spectral analysis of the 'star formation-AGN' mixing sequence and kinematics using diagnostic diagrams with several emission lines. As an illustrative example, we present results from NGC 4258, a spiral galaxy hosting a Low-Luminosity AGN.

Measuring the ISM Content of Nearby, Luminous, Type 1 and Type 2 QSOs Through CO and [C II]

Yuanze Luo
Johns Hopkins University

We present IRAM CO observations for 20 nearby, optically luminous QSO2s and SOFIA [C II] observations for 10 QSOs (five QSO2s and five QSO1s). We examine if and how the ISM content traced by CO and [C II] (e.g., molecular gas mass and gas fraction) differs across LIRGs, QSO2s, and QSO1s. In the traditional evolutionary scenario proposed to explain different types of QSOs, obscured QSO2s emerge from LIRGs and then turn into unobscured QSO1s as the black hole clears out the obscuring material in a blow-out phase. We investigate the consistency of this theory for our samples. We find that QSO1s and QSO2s are indistinguishable in CO luminosities and CO-derived gas mass and gas fraction. However, the SOFIA [C II] measurements show lower CO/[C II] luminosity ratios for QSO1s than QSO2s and LIRGs, which may suggest that QSO1s contain extra sources of [C II] emission likely tracing neutral atomic or ionized gas. LIRGs display a closer resemblance to QSO2s in CO- and [C II]-properties than to QSO1s. All three types of galaxies have statistically indistinguishable distributions of star formation efficiency. There is no evidence for AGN quenching in our QSOs which form a benchmark sample to compare with QSOs at higher redshifts. The evolutionary scenario might not be correct in the nearby universe, where black holes do not act once in a violent way but are more likely to affect their host galaxies continuously by altering the spatial distribution and phase of the gas.

Resolving the connection between outflows, the ISM, and star-formation in NGC 1266

Justin Otter
Johns Hopkins University

NGC 1266 is a nearby AGN host with radio jets and powerful, multiphase outflows driving shocks throughout its interstellar medium. This galaxy also has a post-starburst stellar population, indicating that star-formation has rapidly and recently been quenched in the disk, despite hosting a substantial molecular gas reservoir. With high resolution multi-wavelength data probing the radio jets, cold molecular gas, warm molecular gas, and ionized gas on scales of ~100 pc, we investigate how the jets and outflows impact the surrounding interstellar medium. In particular, we discuss NIR IFS data from GEMINI-NIFS, revealing the resolved shock structure for the first time as well as providing limits on the extent on the star-formation in this galaxy. The combination of star-formation suppression and powerful, multiphase outflows makes NGC 1266 an ideal case study for understanding the role of AGN feedback in star-formation regulation and quenching.

Evidence for Quenching and Rejuvenation from Combined Swift and LADUMA Observations

Kyle Cook
University of Louisville

Ultraviolet is a known tracer of star formation and GALEX data have frequently been used to find the star formation rates of galaxies. We use the more narrow Swift UVOT filters to infer recent star formation histories for comparison to the gas reservoir traced by HI data from the Looking at the Distant Universe with the MeerKAT Array (LADUMA) survey.

We report three SWIFT detected sources in L-band LADUMA data. We compare their relative HI mass fraction and find two are highly depleted, but one is notably gas-rich. Our working hypothesis is that the two UV-green galaxies are (slowly) quenching, while the UV-blue gas-rich galaxy is in a period of rejuvenation.

The JAXA-NASA XRISM Mission: The promise of high-resolution X-ray spectroscopy

Ann Hornschemeier
NASA GSFC

The X-Ray Imaging and Spectroscopy Mission (XRISM), an international JAXA/NASA collaboration including participation from ESA, is a recently-launched (September 2023) advanced X-ray observatory capable of carrying out a science program that will address some of the most important questions in astrophysics in the 2020s. XRISM is essentially a rebuild of the Hitomi (Astro-H) spacecraft that was lost due to an operational mishap early in the mission in 2016. Resolve, the primary instrument on XRISM, is a high-resolution, non-dispersive X-ray spectrometer operating between 0.3-12 keV, providing high-resolution (~5 eV) spectroscopic capabilities in this critical energy band with a response peaking around the ubiquitous 6.4 keV Fe K-alpha line. A wide-field imager, Xtend, will offer simultaneous coverage over nearly a 40' square field of view, with ~1' spatial resolution.

XRISM will study all manner of astrophysical objects, including galaxies and clusters, AGN, X-ray binaries, supernova remnants, transient phenomena, stars, and the interstellar medium. In the area of star formation, it will answer many questions, not the least of which is the nature and velocities of hot outflows in nearby starburst galaxies. This poster highlights some of the early (commissioning and calibration phase) observations by this mission, which show excellent performance by the Resolve instrument. Following the calibration phase and a six-month performance verification phase, XRISM will enter the General Observer (GO) phase, in which it will remain for the duration of the mission. Funding will be available from NASA through the GO phase to US-based PIs, with the first proposals due for Cycle 1 just before this conference.