
# Abstracts

## *Tuesday 8 September:*
## *Star Formation & Gas Content*
## *Morning session (10am-12pm)*

**Lihwai Lin - (INVITED), ASIAA**

*Scaling relations in main-sequence and green valley galaxies with the ALMaQUEST survey*

Recent spatially-resolved observations have revealed that the keys to understanding the correlations among global quantities (e.g., star formation rate, stellar mass, gas mass) lie in the understanding of local processes. Using the ALMA-MaNGA QUEnching and STar formation (ALMaQUEST) survey, we have shown that each pair of the three variables among surface densities of star formation rate (Sigma_SFR), stellar mass (Sigma_M*), and gas mass (Sigma_Mh2) form a tight relation for star-forming spaxels in main sequence galaxies, i.e., the resolved star-forming main sequence (rSFMS: Sigma_SFR vs. Sigma_M*), resolved Schmidt-Kennicutt relation (rSK: Sigma_SFR vs. Sigma_Mh2), and resolved molecular gas main sequence (rMGMS: Sigma_Mh2 vs. Simga_M*). The rSFMS has a larger scatter and could be a natural consequence of the other two relations. In this talk, I will also discuss how the scaling relations of green valley galaxies are compared to those of the main sequence and its implications in the quenching processes.

**Jake Bennett – Institute of Astronomy, University of Cambridge**

*Resolving the effect of cold gas accretion and shocks on high-redshift galaxy formation*

Recent cosmological galaxy formation simulations have found that potentially copious amounts of gas do not shock heat in the circumgalactic medium (CGM) and virialise, but instead deliver cold gas from the cosmic web directly onto galaxies. This significantly changes how galaxies are built up, leading to high central mass deposition rates and hence requiring strong feedback to prevent excessive star formation. However, these simulations typically do not focus their numerical resolution on resolving structure accretion shocks and the CGM, potentially leading to inaccuracies in halo accretion histories.

Using novel computational methods within the moving mesh code AREPO, we can now target numerical resolution to more accurately resolve accretion shocks on-the-fly. This allows us to run full cosmological simulations of high redshift massive galaxy assembly at much higher resolution, to investigate how this changes gas streams passing through the CGM.

Better resolution of cold, dense, accreting filaments can have an impact on the locations and rates of star formation, making predictions for high redshift haloes that could be accessible to observations from JWST. This method also leads to increases in the spatial resolution within the wider CGM, hence allowing not only cosmic inflow but also the multi-phase structure, clumpiness and metal enrichment of galactic outflows to be captured accurately. This can then be compared against ALMA and MUSE observations.

**Jindra Gensior - Heidelberg University**

*Heart of Darkness - How galactic dynamics suppress star formation in galaxy spheroids*

Recent observations point towards a decreasing gas fraction and a low star formation efficiency (SFE) as the key drivers for star formation (SF) quenching in galaxies. However, what drives this SFE decrease, especially in early-type galaxies, is unclear. One proposed mechanism, morphological quenching, suggests that the global galactic environment can affect the gas dynamics such that SF is heavily suppressed.

I will present a suite of hydrodynamic simulations of isolated galaxies, which includes a new sub-grid SF model capturing the influence of galactic dynamics on the SFE. The parameter space considered ranges from disc galaxies to spheroids, with initial gas fractions between 1-20%. This enables a detailed exploration of how differences in the gravitational potential/morphology change the properties of gas and SFE and how it interlinks with the gas fraction.

I show that shear generated by the deep gravitational potential of bulges can suppress SF in the central regions of galaxies by altering the dynamical state of the gas, rendering it supervirial. This dynamical suppression of SF is enhanced at higher stellar surface densities and lower gas fractions. Furthermore, I demonstrate that the resultant ISM structure (gravitational stability, resulting clumpiness, velocity dispersion) is also strongly affected by gas fraction and morphology. Together, these physical mechanisms drive the simulated spheroid-dominated galaxies off the main sequence, into the quenched population.

**Michaela Hirschmann - DARK/Niels Bohr Institut, U. of Copenhagen**

*Nebular emission lines of IllustrisTNG galaxies over cosmic time: signatures for galaxy quenching*

We present a detailed analysis of statistical and spatially resolved emission line properties of simulated galaxy populations at different cosmic epochs. The theoretical strong emission lines are derived from coupling "new-generation" nebular models accounting for photo-ionization due to young stars, AGN, post-AGB stellar populations and fast radiative shocks to galaxies in the IllustrisTNG simulations. The location of line ratios of simulated galaxies in BPT diagrams agree well with observations of both star-forming and active local SDSS galaxies. Shock- and Post-AGB-dominated galaxies (up to 20% at low redshifts) can instead hardly be identified via classic BPT diagrams. These galaxy types are mostly systems in the quenching phase or already completely retired (due to AGN feedback). Investigating the evolution of BPT diagrams, we find that the decrease in SFRs at a given galaxy stellar mass from high to low redshift is mostly responsible for the observed decrease in [OIII]/Hb. We additionally highlight the multifaceted imprint of galaxy quenching in projected 2D nebular emission line maps, such as (i) central Ha deficiencies and/or reduced extent of Ha emission, (ii) steep [NII]/Ha gradients, and (iii) extended low ionisation emission (due to Post-AGB stellar populations). Finally, prospects will be given, to what extent confronting these synthetic observables with recent IFU observations out to z~3 can put strong constraints on the AGN model adopted in simulations.

**Manuela Bischetti - INAF Osservatorio Astronomico di Trieste**

*Linking extreme star formation, molecular gas properties and mergers around luminous quasars at z~2-5*

I will report on the first systematic study of cold gas and star formation properties in the host-galaxies of hyper-luminous (L_Bol > 47.5 erg/s), radio-quiet quasars, with the aim of probing the interplay between nuclear activity and ISM in the most-massive (M_BH > $10^9$ M_Sun), highly accreting supermassive black holes back at z~2.5-5.

I will show that intense star formation activity is having place in their host-galaxies at (AGN-corrected) rates of 500-1000 M_Sun/yr, able to exhaust molecular fuel in only few Myr. Moreover, the combination of high-angular resolution ALMA + NOEMA + JVLA observations of CO(1-0) and high-J CO rotational transitions has revealed an extreme molecular gas excitation in these sources. I will discuss the lower gas fraction found in all these QSOs compared to z~2-3 MS galaxies within the context of AGN-galaxy coevolution and AGN feedback.

Indeed, (sub-)millimetre observations revealed to be a unique tool in probing galaxy assembly around luminous quasars, ~80% of which is “in good company” of massive, nearby (< 40 kpc) companion galaxies.

**Ute Lisenfeld - University Granada**

*Molecular gas in the most massive spiral galaxies*

Super spirals represent a very rare population of massive disk galaxies that have not quenched star formation. These spiral galaxies are extreme by many measures, with r-band luminosities of L = 8–14 L*, stellar masses of 2-6×10^11 M⊙, and giant isophotal diameters of D25 = 55–134 kpc. Their specific star formation rate places them on the star-forming main sequence.

Super spirals are excellent objects to test galaxy evolution. Their extreme properties provide a unique opportunity to extend studies of disk galaxy scaling laws to an entirely new regime, normally occupied by giant elliptical galaxies. Super spirals show a break in the BTFR at very high mass, with a lower baryonic mass compared to the dynamical mass. This implies that when disk galaxies build up to halo masses > 6 × 10^11 M⊙, they accrete inefficiently, restricting the amount of gas available for star formation, and leading to the observed break in the BTFR. An alternative possibility would be that SF is inefficient at these high masses so that less stellar mass is built up.

We recently observed a sample of 24 super spirals in CO(1-0) with the IRAM 30m telescope which allows for the first time to include the molecular gas content in the analysis. I will present and discuss the new results which suggest that the SF and molecular gas fraction are not considerably different from lower mass objects, and that the deviation from the BTFR holds when taking the total gas amount into account.

## *Tuesday 8 September: Star Formation & Gas Content Afternoon session (3pm-5pm)*

**Sara Ellison - (SOC), University of Victoria**

*Complexity and scatter in kpc-scale star formation scaling relations in ALMaQUEST*

The ALMA-MaNGA QUEnching and STar formation (ALMaQUEST) Survey has obtained ALMA CO(1-0) observations of 46 MaNGA selected galaxies in order to map molecular gas and star formation on kpc-scales in the nearby universe. Based on thousands of individual kpc-scale elements, we confirm that the surface densities of molecular gas, star formation rate and stellar mass form tight pair-wise scaling relations, commonly referred to as the resolved star-forming main sequence (rSFMS), resolved molecular gas main sequence (rMGMS) and resolved Schmidt-Kennicutt (rSK) relation. In this talk, I will use ALMaQUEST Survey data to demonstrate that, despite these tight relations, there is significant galaxy-to-galaxy variation in the shape and normalization of these scaling laws and hence none of them is truly universal. Furthermore, I show that the scaling relations of `retired' galaxy regions that have recently ceased to form stars have a rMGMS that is distinct from the star-forming regions, even within a given galaxy, indicating that depletion of the gas reservoir is associated with the quenching process. Finally, I will investigate the relative roles of gas depletion and star formation efficiency in regulating star formation in nearby galaxies.

**Fakhri Zahedy - Carnegie Observatories**

*The Gas-Rich Circumgalactic Medium of Massive "Red and Dead" Galaxies*

While significant progress has been made in understanding galaxy evolution, a self-consistent explanation for the diffuse gas surrounding galaxies (the circumgalactic medium, CGM) still eludes us. Particularly puzzling is the high incidence of cool (T~10^4 K) gas in the CGM of massive quiescent galaxies, contrary to theoretical expectation that the gas is predominantly hot (T>10^6 K). Characterizing the physical properties of the CGM of massive ellipticals is crucial to understand the co-evolution of galaxies and gas over time. I will highlight results from our latest observational studies of diffuse gas within and around distant (z~0.5) massive ellipticals. Despite their quiescence, massive ellipticals have as much cool gas in their CGM as star-forming L* galaxies. Furthermore, large variations in gas metallicity, chemical abundance pattern, and density observed within the halos of individual galaxies indicate that the CGM is a multi-phase mixture of gas with different enrichment histories. In particular, the observed elemental abundance pattern of the gas indicates that the inner halo is significantly influenced by feedback from Type Ia supernovae, whereas gas in the outer halo (>100 kpc) likely originates from accretion from the intergalactic medium. These new observational results provide critical insights into the interplay between accretion and feedback in massive quiescent galaxies, which is critical to understanding quenching processes in massive galaxies.

**Mallory Thorp – University of Victoria**

*Spatially Resolved Properties of Post-Merger Galaxies with MaNGA and ALMA*

Galaxy mergers drastically alter the star-formation rates and gas-phase metallicities of their constituents, playing an integral role in galaxy evolution. Large galaxy surveys are needed to perform statistically robust investigations of these changes, and until recently most large surveys have been limited to measurements of global properties. The advent of integral field spectroscopy (IFS) provides the novel opportunity to study star-formation rate and metallicity on a kpc-scale, revealing the spatially resolved changes result from galaxy mergers that until recently have remained obscured. We present the first statistically significant study of spatially resolved star-formation rates and metallicities of post-merger galaxies from the Mapping Nearby Galaxies with Apache Point Observatory (MaNGA) IFS survey. We quantify the changes in both properties resulting from a merger event as a continuous radial profile, while also addressing the limitations of this method in capturing kpc-scale changes, particularly for highly asymmetric post-merger galaxies. In conjunction with this analysis, we inspect how changes in star-formation rate correspond to variations in molecular gas measurements from the Atacama Large Millimeter Array (ALMA). By combining optical IFS observations with resolved molecular gas measurements, we determine whether the enhanced star-formation in galaxy mergers is the result of a higher molecular gas fraction or an increased star-formation efficiency.

**Jorge Zavala - The University of Texas at Austin**

*Studying the gas content and star formation activity in galaxy proto-clusters: evidence of early environmental quenching?*

We obtain a census of molecular gas mass (via ALMA continuum observations) in ~70 star-forming galaxies within two Coma-like progenitor structures at z=2.10 and 2.47. Combining these measurements with multiwavelength observations and spectral energy distribution modeling, we characterize the gas mass fraction and the star formation efficiency, and infer the impact of the environment on galaxies' evolution. Our analysis showed that, at the probed evolutionary stage of these systems, the star formation efficiency of most of the protocluster members are similar to those found for coeval field galaxies and are in agreement with the field scaling relations, although, a nonnegligible fraction of the less massive systems might have enhanced efficiencies. Interestingly, a large number of massive, red and gas-poor galaxies are found within the proto-cluster structures. Given that these protoclusters have not yet collapsed, these results suggest that quenching before virialization, also known in the literature as galaxy preprocessing, might be an important mechanism related to the environmental quenching. These results will be presented among further constraints on the environmental quenching timescale.

**Sirio Belli - CfA, Harvard and Smithsonian**

*Quenching, Rejuvenation, and Molecular Gas at z~1*

Cold molecular gas represents the fuel for star formation and plays a key role in galaxy quenching. However, measuring the molecular gas content in massive galaxies is observationally challenging at high redshift. Using the NOEMA interferometer, we obtained deep sub-mm observations of CO emission in three massive galaxies at z~1 that are in the process of quenching. High-quality optical spectroscopy from Keck allows us to constrain the star formation history of these galaxies, revealing a remarkable diversity: one system shows evidence of rejuvenation; while another one was quenched on a very rapid timescale. This small yet unique sample will help us understand the relation between molecular gas, star formation, and quenching in massive galaxies at z~1.

**Kate Rowlands - Space Telescope Science Institute**

*Resolving the quenching of star formation in post-starburst galaxies*

One key problem in astrophysics is understanding how and why galaxies stop forming stars. The exact mechanisms that lead to the disruption of the gas supply, the relative importance of different quenching mechanisms, and the timescales involved are still poorly understood. Post-starburst galaxies are an ideal laboratory to study the galaxy transition process as they have undergone a recent, rapid shutdown in star formation. My recent work showed that post-starburst galaxies are not completely devoid of gas, which challenges the rapid quenching mode thought to form the quiescent population. I will present what the stellar, gas and dust properties of post-starburst galaxies reveal about the processes causing galaxies to transition from star forming to quiescent. Spatially resolved observations from the MaNGA integral field spectroscopic survey and ALMA observatory are providing new insights into mechanisms of star-formation suppression and gas cycling in galaxies at a crucial point in their evolution.

## *Wednesday 9 September:*
## *Chemical Composition, Structure, & The Role of Environment*
## *Morning session (10am-12pm)*

**Francesco Belfiore - (INVITED), ESO**

Connecting chemical abundances with star formation histories in large galaxy surveys

Chemical composition is a powerful tracer of the star formation history of galaxies. Spectroscopic surveys have given us access to detailed analysis of the stellar populations of passive galaxies and are pushing our knowledge of the chemical make-up of star-forming galaxies at low and high-redshift. Connecting star-forming and passive populations across cosmic time, and therefore drawing a coherent picture of the quenching process, remains, however, a difficult task. In order to overcome progenitor bias a theoretical framework is needed, which correctly reproduces both the cosmic star formation and chemical evolution history. In this review talk I will discuss recent observational work and draw a connection to the predictions of both analytical models and hydrodynamical simulations. Despite lingering systematic uncertainties, I aim to show that studying the chemical make-up of stars and gas in galaxies may shine new light on the timescale of the quenching process. In particular, I will show how the relation between stellar mass, star formation rate and metallicity may be interpreted in this context. Finally, I will summarize the role of future facilities aimed at obtaining spectroscopy of intermediate and high-redshift galaxies and the opportunities they offer to draw a coherent chemical evolution history of the Universe.

**Sonali Sachdeva - Kavli Institute for Astronomy and Astrophysics, Peking University (KIAA-PKU)**

*Correlation of bulge transformation in disc galaxies with the gradual decrease in their stellar activity.*

The speaker will present their latest results which demonstrate that as disc galaxies accumulate more mass, their central stellar mass density increases, bulge type transforms, stellar population ages and stellar activity recedes. These results have been derived after performing careful 2D mass-based structural (bulge + disc) decomposition of all disc galaxies (1263) in the Herschel imaging area of the Stripe82 region using Ks-band images from the latest VICS82 survey. The scaling relations thus derived are found to reflect the internal kinematics and are employed in combination to select an indubitable set of classical (CBD) and pseudo bulge hosting disc galaxies (PBD). The rest of the galaxies (<20%) whose bulges could not be stringently classified are marked as discs with "interim" bulges (IBD). PBDs and CBDs exhibit clear bimodality in terms of all structural and stellar parameters. All PBDs are blue and star-forming and all CBDs are red and quiescent with less than 5% transgressions. IBDs are intermittent to PBDs and CBDs in all cases suggesting that disc galaxies in transition from pseudo (star forming) to classical (quiescent) stage host interim bulges. Although IBDs are redder than PBDs, their SFR and sSFR is similar, suggesting that either they are dust reddened or have composite populations. All scenarios lend credence to the argument that bulge transformation and recession of stellar activity occur smoothly and simultaneously in disc galaxies with time.

**Peter Watson - University of Oxford**

*The [α/Fe]-σ Relation as a Function of Mass and Environment*

Amongst others, Thomas et al. (2005) and McDermid et al. (2015) have shown that massive early-type galaxies (ETGs), with σ ≥ 80 km/s, obey a tight empirical relation between stellar alpha-to-iron abundance ratio, [α/Fe], and σ. This implies that massive galaxies experience shorter bursts of star formation, i.e. rapid quenching. In addition, although previous works have shown that low-mass ETGs may be quenched by environmental processes (e.g. Gunn & Gott, 1972; Moore, 1996), which are different from the quenching mechanisms of massive galaxies, the behaviour of this relation at low masses remains controversial (eg. Annibali et al., 2011). Using data from the SAMI Galaxy Survey, we explore this relation to masses as low as M* < 10^8.5 M_solar, determining [α/Fe] via Lick/IDS index measurements in central apertures. Since the survey samples galaxies over a wide mass range (10^8.5 < M_* < 10^12 M_solar), we are able to directly corroborate previous works at the higher end of the mass scale. In addition, while Thomas et al. concluded that the [α/Fe]–σ relation is independent of environment, McDermid et al. showed a higher [α/Fe] for galaxies in cluster environments than in the field. As the target selection for the SAMI Galaxy Survey samples nearby field galaxies and the massive galaxies in 8 clusters over a wide mass range, we are able to construct a homogeneous sample of both cluster and field galaxies, allowing us to compare the [α/Fe]–σ relation as a function of environment.

**José Luis Tous - Universitat de Barcelona**

*Spectral classification of S0 galaxies in the nearby universe: a tale of two sub-populations*

In a recent work submitted to MNRAS we review the main properties of objects designated S0. Our aim is to assess the formation channel(s) that these objects may have followed on the basis of the identification of their most relevant physical parameters and the exploration of their possible dependence on the environment. Our approach combines the characterization of the fundamental features of the visible spectrum of 68,043 nearby S0 with the analysis of a set of their global attributes. A PCA has allowed us to reduce the huge number of dimensions of the spectral data to a low-dimensional space facilitating an automated machine-learning-based classification of these objects. This procedure has revealed that galaxies bearing the S0 designation, despite showing similar morphologies, consist of two sub-populations with segregated properties. Compared to the classical absorption-dominated S0, those with significant nebular emission are, on average, less massive, more luminous with less concentrated light profiles, host a somewhat younger, bluer and metal-poorer stars, and avoid regions of high galaxy density. The majority of members of this latter class, which accounts for at least a 25% of the local S0 population, show current star formation levels comparable to those of typical late-type spirals. This suggest that star-forming S0 might be less rare than hitherto believed and raise the possibility of identifying them with plausible progenitors of their quiescent counterparts.

**Adam Carnall - Institute for Astronomy, Royal Observatory Edinburgh**

*The physical properties of massive quiescent galaxies at 1.0 < z < 1.3*

The star-formation histories (SFHs) of high redshift massive quiescent galaxies hold the key to understanding how the first galaxies in the Universe quenched their star-formation. A range of upcoming instruments (e.g. MOONS, PFS, WEAVE) will soon allow us to extend deep spectroscopic observations to statistical samples of quiescent galaxies at high redshift for the first time, allowing us to make precise measurements of their SFHs. In order to take full advantage of the superior data from these instruments, it is important to develop correspondingly superior analysis techniques, moving beyond index measurements to obtain stronger constraints on galaxy SFHs through full spectral fitting. I will introduce Bagpipes, a new public Python code which allows sophisticated model galaxy spectra to be fitted to combinations of spectroscopic and photometric data using rigorous Bayesian statistical methods. I will demonstrate the use of this method to analyse a sample of ultra-deep spectra for massive quiescent galaxies at 1.0 < z < 1.3 from VANDELS, investigating quenching physics at high redshift by constraining the SFHs of these objects and the stellar mass vs stellar age relationship. I will also report on ongoing observational efforts with KMOS to make the first measurement of the stellar mass-metallicity relationship for massive quiescent galaxies at z > 1. Finally I will discuss ongoing efforts to select large photometric samples of massive quiescent galaxies at z > 3 for spectroscopic follow-up with upcoming instrumentation.

**James Trussler – Kavli Institute, University of Cambridge**

*Unveiling the roles of mass, environment and structure in galaxy quenching*

Leveraging on the statistical power of the SDSS, we analyse the chemical properties of tens of thousands of local star-forming, green valley and passive galaxies to investigate how galaxy quenching depends on the internal properties of galaxies (stellar mass), external factors (environment), and how it varies radially within galaxies. We find that the significant difference in stellar metallicity between passive galaxies and their star-forming progenitors implies that for galaxies at all masses, quenching must have involved an extended phase of starvation. In order to best match the observed properties of local passive galaxies, some form of gas ejection has to be introduced in our models, with outflows becoming increasingly important with decreasing stellar mass. By separating star-forming, green valley and passive galaxies, we find that the environment leaves a much weaker imprint on the stellar populations of galaxies than was previously thought. Satellites are only marginally more metal-rich and older than central galaxies of the same stellar mass, with stellar metallicities that show only a weak dependence on halo mass, local overdensity and projected distance. Finally, using MaNGA IFU data, we find that the stellar metallicity difference between star-forming and passive galaxies decreases with radial distance. Therefore, while starvation plays a prominent role in quenching the central regions of galaxies, it plays a less important role in quenching the outskirts.

## *Wednesday 9 September*
## *Chemical Composition, Structure, & The Role of Environment*
## *Afternoon session (3pm-5pm)*

**Joanna Woo - (INVITED), Simon Fraser University**

*Structural Evolution and Quenching*

Quiescence in galaxies correlates strongly with the central density/morphology of their stellar distribution. At least two explanations could be responsible for this relation including dissipative core-building event that feeds an active galactic nucleus (AGN) that quenches the galaxy, as well as inside-out growth by galaxy-wide star formation that is quenched by processes unrelated to the central density. I will present results from the MaNGA IFU survey of local galaxies that suggest that both of these scenarios contribute to the morphology-quiescence relation, suggesting that galaxies follow at least two evolutionary paths while growing, and I will argue, while quenching. Furthermore I will show that hydrodynamical simulations confirm the multiple paths of structural evolution, and present new evidence that these paths are driven primarily by the angular momentum of accreting gas.

**Grecco Oyarzun - UCSC**

*SDSS-IV MaNGA: The impact of environment on the formation of passive central galaxies*

Under hierarchical galaxy formation, environment is critical to the assembly of central galaxies. Yet, observations indicate that their assembly history is dominated by internal processes. In this work, we use SDSS IV MaNGA to search for signatures of environment-driven evolution in the spectra of 985 passive central galaxies. At fixed stellar mass (M), we find centrals in low mass halos (i.e. oversized centrals) to show highly significant spectral differences from centrals in high mass halos (i.e. undersized centrals). To interpret these differences, we turned to stellar population fitting with Prospector and Alf. Around M=10^11Msun, oversized centrals formed at earlier times and in shorter timescales, and have higher central M surface densities than undersized counterparts. This is evidence that oversized centrals formed earlier and in more concentrated halos, implying that galaxy assembly bias dominates at M=10^11Msun. Toward M=10^12Msun, oversized bright central galaxies (BCGs) have younger stellar populations and higher central M surface densities than undersized BCGs. This suggests that BCGs formed their in-situ populations around z=4 and experienced significant merger growth at z<2.

**Carter Rhea, University of Montreal**

*A novel mechanism for the creation of stellar mass in galaxy clusters*

The study of Stellar Formation Rates has long been at the heart of galactic/extragalactic astrophysics. Recent galaxy cluster surveys, such as the South Pole Telescope Survey, have revealed that high redshift (z>1) galaxy clusters, unlike their local counterparts, are regions of intense star formation. Previous studies suggest the buildup of stellar mass through positive feedback mechanisms such as major mergers and ram pressure stripping; however our recent investigation of the massive galaxy cluster SpARCS104922.6+564032.5 reveals a new and unexpected mechanism -- an unrestrained cooling flow. More precisely, the cluster stands out as harboring a still assembling brightest cluster galaxy (BCG) undergoing extreme stellar formation at z=1.7091 (~850 $M_{\odot}$/yr). Here, we present 170 ks (~50 hours) of new Chandra observations. Using several techniques for calculating galactic substructure and proxies of cooling flows, we develop a more coherent image of the mechanism responsible for the rampant stellar formation of the BCG. Our results show the presence of a strong cooling flow cospatial with the region of intense star formation ~50 kpc from the BCG indicating a lack of AGN feedback in the system -- in direct contrast to local counterparts. Moreover, the lack of a mechanism to suppress star formation appears to be providing the ideal environment for a buildup of intracluster light. This demonstrates a novel mechanism for the formation of stellar mass in galaxy clusters.

**Marziye Jafariyazani - Carnegie Observatories, and University of California, Riverside**

*The stellar chemical abundances of the brightest quiescent galaxy at z ~ 2 accompanied by its age and metallicity gradients*

Measuring the chemical composition of galaxies is crucial to our understanding of galaxy evolution models and quenching processes. However, such measurements are extremely challenging for quiescent galaxies at high redshifts, which have relatively faint stellar continuua and compact sizes, making it difficult to detect absorption lines and nearly impossible to spatially resolve them using current ground-based facilities. Yet, gravitational lensing offers the opportunity to study these galaxies at the highest resolution possible. In this talk, we present the full spectral fitting results of MRG-M0138, a lensed quiescent galaxy at z = 1.98 which is the brightest of its kind with an H-band magnitude of 17.1. We measured [Mg/Fe] = 0.51 ± 0.05 and [Fe/H] = 0.26 ± 0.04 which reveal that not only is this galaxy very Mg-enhanced compared to massive early-type galaxies in the local universe, but it is also very iron rich, challenging our current chemical evolution models. We also measured the abundances of 7 other elements and radial gradients in the stellar age, metallicity, and Mg-enhancement for the first time in a z ~ 2 quiescent galaxy. We will discuss the implications of these unique measurements for understanding this galaxy's formation history.

**Alessandro Marconi - Department of Physics & Astronomy, University of Florence**

*Outflow physical properties and star formation quenching*

Feedback from AGN is considered the main physical mechanism quenching star formation in galaxies with powerful outflows. However, while outflows are ubiquitous, their impact on galaxies and physical properties are still poorly known. In particular, we are still missing the smoking gun evidence of AGN-driven outflows quenching star formation. I will present several observational programs targeting AGN host galaxies from low to high redshift and aimed to understanding the physical properties of the outflows and their impact on the host galaxies. At low redshift, I will present a survey aimed at studying the physical properties of outflows in nearby AGN using integral field spectroscopic observations with VLT/MUSE and ALMA. The spatial resolution down to a few tens of parsecs allows to study the ionisation structure of the outflows and the relation between ionised and molecular gas while innovative kinematical modelling allows to accurately constrain geometry and kinematics despite the very complex observed morphologies. At high redshift, I will present results from surveys aimed at studying the impact of outflows on quasar host galaxies, the progenitors of the local massive galaxies, using IFU observations with VLT/SINFONI and ALMA. In particular, I will present evidence for an anti correlation between the presence of fast outflows and star formation activity. Finally, I will discuss how our results fit in the canonical picture of star formation quenching by AGN outflows.

**Sandro Tacchella (INVITED), Harvard-Smithsonian CfA**

*The diversity of building up the quiescent sequence at z~1*

I will show evidence for a diversity of pathways for building up the quiescent galaxy population at early cosmic times. Specifically, I will present observational constraints on star-formation histories and quenching timescales by combining Keck DEIMOS spectroscopic data with >10-band photometry. I will discuss how one can self-consistently fit both photometric and spectroscopic data together with the tool Prospector, which allows fitting for nonparametric star-formation histories and complex stellar, nebular, and dust physics. Although the apparent diversity, we find that the most massive, compact galaxies have formed their stars the earliest and most rapidly. Finally, I will relate these findings to numerical simulations (in particular IllustrisTNG), putting forward that most galaxies not change their morphology significantly during quenching.

# Thursday 10 September:
# The Role of Feedback
# Morning session (10am-12pm)

**Asa Bluck - (SOC), University of Cambridge**

*How do central and satellite galaxies quench? - Evidence for AGN feedback & environmental quenching in the MaNGA IFU Survey*

Understanding why galaxies cease forming stars long before their non-stellar baryon fractions reach zero is one of the major challenges in the theory of galaxy evolution. I will present a new analysis of radial profiles in the offset from the resolved main sequence (Delta SFR), and in luminosity weighted stellar age, for 3500 central and satellite galaxies observed as part of the MaNGA IFU survey. Through an analysis of over 5 million spaxels (spectral pixels), we find evidence for two distinct quenching channels: 1) *Intrinsic quenching*, which is marked by steeply rising radial profiles in Delta SFR indicating *inside-out* quenching; and 2) *Environmental quenching*, which is marked by steeply declining radial profiles in Delta SFR indicating *outside-in* quenching. Intrinsic quenching is most strongly correlated with central velocity dispersion, indicating a plausible link with the central supermassive black hole. Perhaps surprisingly, at a fixed central velocity dispersion, both stellar and halo mass are completely uncorrelated with quenching. Alternatively, environmental quenching is so named in our analysis because it correlates most strongly with local galaxy over-density. Thus, we find strong evidence for two distinct modes of star formation quenching, which operate on very different physical scales and yield clearly distinguishable observational signatures. Finally, we note that central galaxies are most impacted by intrinsic quenching, whereas satellite galaxies experience both environmental and intrinsic quenching, with the dominant quenching mode depending on their stellar mass.

**Yu Qiu - Kavli Insitute for Astronomy & Astrophysics**

*Untangling the Properties and Effects of AGN Feedback in Galaxy Clusters*

Recent observations of some cool-core clusters (CCCs) paint a picture of powerful quasars in their brightest cluster galaxies (BCGs), raising questions about the role of radiative feedback in the evolution of these systems. Motivated by this, we use 3D radiation-hydrodynamic simulations to explore for the first time the joint role of radiative and mechanical feedback from supermassive black holes (SMBHs) in BCGs.

Our simulations highlight a multitude of effects AGNs have on their host galaxy cluster:

(1) The central AGNs transition between radiatively efficient and radiatively inefficient states on timescales of a few gigayears, as a function of the accretion rate.

(2) Mechanical feedback must be present at both low and high accretion rates in order to prevent the cooling catastrophe and its contribution likely accounts for > 10% of the instantaneous AGN feedback power.

(3) Our simulations also reproduce the salient properties of AGN feedback in CCCs, such as jet-inflated cavities, ripples in the intracluster medium, and spatially extended Hα filaments. In particular, we find that AGNs are the main driver for the formation of extended cold gas filaments, and that filaments can be used as a probe of past AGN activity.

**Federica Loiacono, University of Bologna**

*Can AGN outflows contribute to forming the spheroidal component of galaxies?*

Over the last decade, one of the most debated issues in astronomy is the effect of AGN feedback on star formation. According to models, high-velocity winds boosted by AGN may expel large amounts of gas from the host galaxies, thus quenching the star formation activity. On the other hand, recent theories and numerical simulations have suggested that in molecular outflows there could be the physical conditions to form stars by the compression and cooling of the outflowing clouds. This mechanism could have crucial implications on galaxy formation and evolution. In particular, since the stars formed in the outflowing gas would have the kinetic imprint of the wind (i.e. high radial velocity), they could contribute to the building-up of the spheroidal component of galaxies, i.e. bulge, halo or even to the formation of ellipticals. However, the observational evidence is still scanty due to the difficulties in directly detecting stars that are forming in the outflows.

In this talk I will show one of the first evidences of young stars detected in AGN outflows using UV high-resolution spectroscopy of local ultra-luminous galaxies. Because of their high velocity (~ -100 km/s compared to the stars in the disk), these stars could indeed contribute to the formation of the spheroidal component of galaxies. This finding suggests that AGN outflows can also contribute to the transformation of galaxies not only by quenching star formation but also by producing new stars on radial orbits.

**Tiago Costa, MPA**

*Powering galactic super-winds with small-scale AGN winds and radiation*

Feedback from AGN is shaped by elusive physical processes that operate over an extreme range of spatial scales. Since neither the main feedback channels nor the nature of their interaction with interstellar gas have been established, the efficiency of AGN feedback remains unconstrained. In this talk, I will present results from new idealised and cosmological, (radiation-)hydrodynamic simulations performed with the state-of-the-art codes RAMSES-RT and AREPO. These simulations are carefully designed to directly quantify the relative importance of two AGN feedback mechanisms: (i) AGN radiation at galactic scales and (ii) small-scale accretion-disc winds. I will compare the efficiency at which these distinct processes drive galactic outflows and inhibit star formation in their host galaxies. I will show that, while simple at the scale of injection, radiation pressure and small-scale winds result in powerful outflows with complex morphologies and velocity structures. While radiation pressure drives significant gas masses outwards if the galactic nucleus is optically thick to IR radiation, I will argue that small-scale winds power energy-driven bubbles that both launch very dense gas but also suppress halo gas accretion, ultimately leading to stronger feedback. I will quantify the properties of the resulting multi-phase outflows, focussing on how their velocity and energetics relate to the AGN luminosity, gas phase as well as the properties of the small-scale winds that power them.

**Michele Ginolfi, University of Geneva**

*Star formation-driven feedback and circumgalactic enrichment in the Early Universe*

Current models of galaxy formation widely agree on the key role of star formation feedback in regulating the evolution of galaxies across the cosmic time, although observational evidence is still limited to local and intermediate-redshift galaxies.

I will present recent pioneering studies of the galactic feedback efficiency in the Early Universe, exploiting observations of a large sample of normal star-forming galaxies at z~4-6, drawn from the "ALMA Large Program to INvestigate [CII] at Early times" (ALPINE) survey (that I will shortly introduce, highlighting some new key results relevant to this conference).

We discover signatures of star formation-driven winds in the high-velocity tails of the stacked [CII] profile and estimate mass-loading factors of the order of unity, thus suggesting that star formation feedback does not play a dominant role in rapidly quenching high-z galaxies.  We also detect [CII]-halos extended on physical scales of ~20 kpc around highly star forming galaxies, tracing circumgalactic gas likely enriched by past outflows.

These findings suggest that outflows and gas exchanges with the circumgalactic medium are at work in regulating the star formation and the baryon cycle of galaxies already at very early epochs.

**Charlotte Avery, University of Bath**

*Incidence, scaling relations and physical conditions of ionised gas outflows in MaNGA*

We investigate ionised gas outflows driven by star-formation and low-luminosity AGNs among 2298 nearby (z ~ 0.03) galaxies in the MaNGA IFU galaxy survey. Significant evidence for outflow activity is found within 343 objects. Outflows are probed using a two-Gaussian decomposition of the Hβ, [OIII], Hα, [NII], and [SII] emission line profiles extracted within apertures of different size. We find most outflows to be centrally concentrated, exhibiting line ratios consistent with shock excitation and electron densities extending to higher values than found for the disk gas. A subset of wind galaxies further shows evidence of enhanced attenuation of the outflowing gas component.

Strong correlations between outflow properties and internal properties of the host galaxies are revealed, for which we provide scaling relations to compare to feedback processes in galaxy evolution models. We quantify the strong dependence of mass outflow rates on star formation activity and AGN luminosity, and find mass loading factors to depend sensitively on central stellar concentration. The observed dependencies of outflow rate and mass loading on disk inclination further shed light on wind geometries.

Massively multiplexed resolved IFU observations prove a powerful means to characterise the strength and incidence of outflow-feedback at play across the nearby galaxy population, and provide insight into the impact of feedback in typical nearby galaxies on quenching.

## Thursday 10 September:
## The Role of Feedback
## Afternoon session (3pm-5pm)

**Julie Hlavacek-Larrondo - (SOC), University of Montreal**

*The role of AGN feedback in galaxy clusters for the last 10 billion years*

Clusters of galaxies are fantastic laboratories for understanding the physics of AGN feedback. They play a pivotal role in our understanding of jet-mode feedback by demonstrating that AGN-driven jets can inject profound amounts of energy into their surroundings via shock fronts, sound waves and turbulence, in addition to driving powerful molecular outflows and metals out of galaxies. In this talk, I will review the current state of this field with a particular emphasis on the evolution of such feedback in the last 10 billion years. I will also present new state-of-the-art VLA observations of the Perseus cluster of galaxies, as well as a detailed study that focusses on the statistical properties of large scale radio emission in clusters. Both these studies reveal new physics about the nature and properties of AGN feedback.

**Bryan Terrazas - Harvard-Smithsonian CfA**

*Exploring the link between star formation activity and black hole mass in galaxies*

Observational evidence from across the electromagnetic spectrum supports the current leading theory that black hole feedback causes quiescence in massive galaxies. However, the exact form of this feedback and how it operates remains uncertain. I will describe observational results from a sample of 91 local galaxies with dynamical black hole masses and show that the black hole-stellar mass relation has significant scatter which correlates strongly with the galaxy’s degree of quiescence. In fact, for this diverse sample ranging from massive ellipticals to isolated spirals, the specific star formation rate is a smoothly decreasing function of the black hole-stellar mass ratio. These results present a powerful diagnostic tool with which to test black hole feedback and its effects on star formation in the latest galaxy formation models. I will show how the relationship between black hole mass, stellar mass, and star formation rate encodes information on the physics of quiescence via black hole feedback in simulations such as IllustrisTNG, EAGLE, and L-Galaxies, thereby allowing a novel interpretation of the observations.

**Giacomo Venturi, Pontificia Universidad Catolica de Chile**

*Dissecting ionised gas outflows and feedback in nearby AGN and mergers through integral field spectroscopy*

AGN outflows are thought to play a major role in shaping the properties and evolution of host galaxies, by sweeping away the gas and quenching star formation.

In this context, our MAGNUM survey aims at investigating in detail the properties and driving mechanisms of galactic outflows and their interplay with star formation processes in nearby Seyfert galaxies which, due to their vicinity, are ideal laboratories to carry out such a study.

Thanks to its unique combination of large field of view and spectral coverage, VLT/MUSE allowed us to map the ionised gas down to ~10 pc in several transitions revealing ubiquitous kpc-scale outflows and to dissect their properties (such as velocity, mass outflow rate, density etc…).

Furthermore, we detected an extended puzzling jet-ISM interaction phenomenon in several jetted sources, which we investigated by matching MUSE data with simulations, indicating that also low-power jets in “radio quiet” AGN can have an active role in driving outflows and impacting on the host galaxy. We also found evidence of star formation induced by outflows.

Finally, by targeting galaxies in different merging stages, we investigated the role of mergers in launching outflows and exerting feedback on the host galaxies, and studied the outflow acceleration and propagation mechanisms from nuclear up to galactic scales, through both MUSE wide-field and AO-assisted narrow-field observations.

**Alice Concas - University of Cambridge**

*Unveiling the role of ejective feedback from z ~ 2 to the present.*

Galaxy formation models suggest that massive gas outflows driven by stellar and AGN feedback may quench star formation in galaxies. We test this ejective scenario investigating the statistical incidence of gas outflows across cosmic time. We use 600k spectra from the SDSS at z=0 and IFU data at z=2 from the KLEVER survey with VLT/KMOS. We adopt a stacking approach of rest-frame optical spectra as a function of stellar mass, SFR, AGN activity, and disk inclination. At z=0, we investigate the kinematics of ionised gas with the [OIII]λ5007 and H-alpha emission lines and of neutral gas with the NaD absorption doublet. We find that (1) ionised gas outflows are only observed in AGN-dominated galaxies and not in purely star-forming ones; (2) neutral gas outflows are observed independently of the AGN activity but only at SFR>10 Msun/yr; (3) neutral gas outflows display a clear dependence on galaxy inclination, pointing to a disk origin; (4) both ionised and neutral outflows have velocities smaller than the galaxy escape velocity, suggesting that the gas will likely fall back into the galaxy. At z=2, we compare the kinematics of [OIII]λ5007 and H-alpha emission lines finding clear gas outflows in both tracers in AGN-dominated galaxies, while the incidence of galactic winds remains unclear in purely star-forming ones. We discuss the implications of our results on theoretical models of galaxy formation.

**Tjitske Starkenburg, CIERA Northwestern University**

*The populations of star forming and quiescent galaxies in large-scale cosmological simulations*

The galaxy star formation sequence, whether predicted from simulations or observed, varies depending on the dataset and the tracers used to measure star formation rates. As a result the quiescent population of galaxies varies significantly from dataset to dataset and across different definitions of ‘quenching’ and ‘quenched’.

We explore star formation and quiescence of galaxies in a large observational dataset and 6 large-scale cosmological simulations. We carefully build mock galaxy spectra for all (~3e5) simulated galaxies and (re)measure star formation rates and quenching indicators in the same way as done for observations.

Using this wealth of spectral data, we describe the galaxy star forming sequence and the populations of star-forming, quiescent, and in-between, isolated galaxies in theoretical predictions, mock observations, and observational data, and compare these populations. Because all cosmological simulations use different implementations of relevant physics, we can start to connect the different quenching mechanisms in the simulations to trends in the observational indicators and to galaxy properties in the simulations. Additionally, we combine our observational and theoretical quenching knowledge to study how consistent definitions of quenching are, and to provide comparisons and conversions for a number of observational quenching and quiescence indicators.

**Gareth Jones - University of Cambridge**

*A Sub-Dominant Starburst-Driven Outflow at z~5.7*

In the early Universe (i.e., z>4, less than 1.5Gyr after the Big Bang), a number of galaxies have been observed with high star formation rates (SFR>1000 solar masses per year). The cause of these extreme starbursts is ambiguous (e.g., major mergers, filamentary accretion of pristine gas). Regardless of the origin, it is clear that this activity may not continue indefinitely, as the gas depletion timescales of these objects are on the order of tens of Myr. This raises the question: for the brightest starbursts in the observable universe, what is the primary process that controls their star formation history: environmental effects (group harassment, minor/major merging), gas depletion via star formation, secular gas inflow via filaments, or feedback? To examine this, we observed a blueshifted water absorption line of a hyper-starburst (SFR~3600Msol/year) at z~5.7 (~1Gyr after the Big Bang) with ALMA, finding evidence for a molecular outflow. Previous radio and x-ray observations reveal very little evidence for an AGN, so this outflow is likely starburst-driven. Using a simple spherical outflow model, we find a mass outflow rate of ~500Msol/year, and a mass loading factor of <0.3 under the most conservative assumptions. Thus, despite the high SFR of this source, the outflow has little effect on the gas depletion of this source. The runaway star formation here will use all available fuel in 30Myr, resulting in a passive galaxy at z~2-4, unless new gas in accreted.