# From Black Hole to Environment:

# Galaxy Evolution over Multiple Wavelengths

Barton Theatre, Crawford School of Business, Australian National University

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# TALK ABSTRACT BOOKLET

**Session I: Galaxy Cluster I**

**Chair: Ivy Wong**

**Melanie Johnston-Hollitt (Invited Review)**
Victoria University of Wellington

*Galaxy groups, clusters, and large scale structure: open questions and opportunities*

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**Scott Barrows**
University of Colorado

*Evolution of Stellar Populations and Supermassive Black Holes in Late-Stage Galaxy Mergers*

The star-formation (SF) that evolves galaxies can be affected by feedback processes from stellar winds or active galactic nuclei (AGN). Numerical simulations suggest that both SF and AGN feedback can be enhanced in merging galaxy systems and that both may be correlated with the merger stage. While observational studies have confirmed these trends at early merger stages (>10 kpc), constraints at smaller separations - when the probability of AGN triggering is predicted to peak - have been tenuous due to difficulties in identifying such systems. Furthermore, correlated SF and AGN enhancements have been observationally elusive, potentially due to a time delay as suggested by simulations. To test these predictions, we have used a combination of X-ray and optical imaging to identify late-stage mergers (<10 kpc) hosting AGN. Then, using a multi-wavelength set of photometry from UV to IR wavelengths, we have obtained estimates of specific star-formation rates (sSFRs) and stellar ages for a range of merger stages. We see evidence for enhanced sSFR correlated with the merger mass ratio, implying the presence of merger-induced SF. However, we also see evidence for the late-stage mergers to have suppressed sSFRs and older stellar populations compared to matched control samples. This result suggests that we are observing these systems after their peak in merger-induced SF and with relatively evolved stellar populations. With increasingly later merger stages, we see evidence for decreasing sSFR enhancements but also an increase in the frequency of AGN triggering. The contrasting behavior of SF and AGN at late-merger stages, combined with age estimates for the stellar populations, provide evidence for a time delay between the peak in SF and AGN activity that is consistent with predictions from simulations. Finally, radial color gradients in these systems show that the galaxy colors generally become bluer with increasing radius similar to early-type galaxies. This observation suggests that any enhanced SF is likely occurring at large radii and that the photo-ionization detected in the nuclear regions is dominated by the AGN. Our procedure for selecting galaxy mergers has proven effective at probing regimes of small nuclear separations while providing measurements of both SF and AGN

enhancements. Larger samples constructed in the same manner will be excellent for testing numerical predictions of super-massive black hole and galaxy co-evolution through mergers.

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**Martin Krause**
Centre for Astrophysics Research, University of Hertfordshire

*Jets Signify Close Binary Supermassive Black Holes*

Various jet-related observations from radio to gamma rays and from the parsec scale to almost Megaparsec scale have produced circumstantial evidence that point towards binary black holes. I will give an overview over the different kind of observations and their interpretation, and present individual examples with multiple pieces of evidence that their jets originate from a close binary supermassive black hole. Taken together, the evidence suggests that supermassive black hole binaries are widespread and linked to powerful jets. There is also evidence for higher multiplicity. This is in line with a connection of jets to galaxy mergers. The closest jet sources might be detected by next generation pulsar timing arrays if indeed they contain close black hole binaries.

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**Session II: Galaxy Cluster II**

**Session Chair: Sukyoung Yi**

**Sarah Brough**
University of New South Wales

*Environment or Mass? The Kinematic Morphology – Density Relationship*

A strong relationship between the kinematic morphology (degree of rotational support) of early-type galaxies and environmental density has been claimed by the ATLAS3D integral field survey. This relationship would suggest that environment has a role in the spin down of early-type galaxies. I will present analysis of the kinematic morphology — density relationship with a significantly larger sample from the 8 galaxy clusters observed by the SAMI Galaxy Survey. We find that, once stellar mass is also considered, kinematic morphology is a strong function of stellar mass rather than of environmental density. The spatial location of the slow-rotating galaxies at the centres of the clusters and cluster sub-structure suggests that they form in the lower-density group environment and then fall into clusters through dynamical friction.

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**Lauranne Lanz**
Dartmouth College

*AGN in Early Phases of Galaxy Transitions*

The role of AGN in the transition of galaxies from actively star forming to quiescence is still not fully understood, and is particularly challenging to study for AGN that are weak or hidden by obscuration or host dilution. The Shocked Post-starburst Galaxy Survey (SPOGs) selects quenching galaxies still containing shocks and molecular gas based on their optical line diagnostics. SPOGs catches galaxies at an earlier stage of transition than classical post-starburst selection criteria, providing a crucial window into the role of AGN in this early phase of transformation. We recently obtained a deep Chandra observation of the proto-typical SPOG NGC1266 combined with a NuSTAR observation as well as Chandra observations of a set of SPOGs showing enhanced IR emission relative to their molecular content. I will discuss the insights obtained about the characteristics of AGN in SPOGs and the implications on the role of AGN in galaxy transitions.

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**Tiffany Day**
Macquarie University

*Major Cluster Mergers as Drivers of Galaxy Evolution and Transformation*

Clusters of galaxies are the largest and most massive virilised objects in the observable Universe, growing hierarchically over cosmic time by the accretion of surrounding gas, dust and matter, including the infall of individual field galaxies or groups of galaxies. More rarely, clusters of galaxies grow by means of a gravitational merger between two or more existing clusters of galaxies, providing the most extreme example of this hierarchical formation scenario. In order to understand the kinematic state and dynamical history of major cluster mergers, and use that advancement to understand galaxy properties and how they evolve over time, we will consider this most extreme example - a major cluster merger - as this will exemplify the physical processes governing infalling galaxies, and reveal clues as to their differing properties. This talk focuses on the galaxy cluster Abell

2744, a massive cluster at a redshift of z = 0.3, and one of the most complicated merging systems known. Using both radio continuum data and optical spectroscopy of Abell 2744, I will present my preliminary results obtained during the first year of my PhD.

## Session III: High Redshift Universe

## Session Chair: Sarah White

**Elisabete da Cunha**
Australian National University

*The TAIPAN Galaxy Survey: Towards a new Galaxy Evolution Sample in the Local Universe*

I will present the Taipan galaxy survey, a new multi-object spectroscopic survey starting in late 2017 that will cover 2pi steradians over the southern sky and will obtain optical spectra for about 2 million galaxies in the local Universe ($z < 0.4$) over 5 years. Taipan will use the refurbished 1.2m UK Schmidt Telescope at Siding Spring Observatory with the new TAIPAN instrument, which includes an innovative Starbugs optical fibre positioner and a purpose-built spectrograph. The main science goals of Taipan are: (1) to measure the present-day expansion rate of the Universe, H0, to 1% precision, and the growth rate of structure to 5%; (2) to make the most extensive map yet constructed of the mass distribution and motions in the local Universe using peculiar velocities; (3) to deliver a legacy sample of low-redshift galaxies as a unique laboratory for studying galaxy evolution as a function of mass an environment.

Taipan will have a magnitude limit similar to SDSS, with two major advantages in the Galaxy Evolution field: the ability to characterise the environments down to close galaxy pairs (via multiple field visits and dense field coverage); and the overlap with the WALLABY ASKAP survey, which will provide the HI gas content of the galaxies

We will combine these with spectroscopic and photometric information on the physical properties (stellar masses, star formation rates, AGN activity), and trace the lifecycle of baryons in galaxies from gas reservoirs to star formation.

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**Jacinta Delhaize**
University of Zagreb

*Statistical Studies of Star Formation in AGN to Z~5 from a Combined Infrared and Radio Continuum Perspective*

How, when and why AGN activity can influence star formation within their host galaxies remains enigmatic, yet is essential for a complete understanding of galaxy evolution. We have examined the monochromatic 250-micron infrared luminosities, and by proxy the star formation rates, of a complete sample of 195 radio AGN via a stacking analysis of Herschel ATLAS data. We demonstrate that statistical far-infrared detections of radio AGN are possible out to z~5 and find that the specific star formation rates of these AGN are lower than that of star-forming galaxies on the main sequence. This may indicate that feedback caused by radio AGN activity inhibits star formation in the host galaxy, or, alternatively, that radio-loud AGN are preferentially found in passive galaxies across cosmic time. I will also show how the new, highly-sensitive VLA-COSMOS 3GHz Large Project can complement previous radio continuum surveys to provide an excellent resource for studies of both star formation and AGN activity in galaxies. We have identified around 11,000 radio objects in this survey and have recently made the catalogues publicly available. By combining this data with Herschel PEP and HerMES observations, I will show how the infrared-radio correlation can be used to identify an elusive population of radio AGN out to z~5-6.

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**Colin DeGraf**
**Institute of Astronomy, University of Cambridge**

*Supermassive Black Hole Seeds in Cosmological Simulations*

Supermassive black holes are well understood to play an important role in galaxy evolution, as well as acting as an observational probe reaching back to the very early universe. One of the most uncertain aspects of our understanding of supermassive black holes is the mechanism by which their initial seeds form and the efficiency and frequency with which this occurs, which has the potential to directly impact early galaxy evolution. Using high-resolution cosmological simulations and post-processing of black hole accretion and merger histories, I will discuss which observables are affected by changing the seed prescription. In particular, I will focus on how global properties such as the black hole mass function, global accretion rate density, and the quasar luminosity function depend on the fraction and type (e.g. metallicity and spin parameters) of halos capable of forming SMBH seeds, and the possible constraints we can determine from current and upcoming observational surveys.

## Session IV: High Redshift II

## Session Chair:

**Michael Dopita**
The Australian National University

*Results from S7: The Siding Spring Southern Seyfert Spectroscopic Snapshot Survey*

S7 is an integral field survey of over 130 southern Seyfert and LINER galaxies using the WiFeS instrument on the 2.3m telescope at Siding Spring. The survey is now complete, and the data products have been released to the community. I will summarise the contribution that this survey has made to our understanding of the extended Narrow Line Regions, the Unified model of AGN, star formation, galactic outflows, and accretion by Black Holes in active galaxies.

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**Theresa Falkendal**
ESO

*Evidence for Quenching in High Redshift Radio Galaxies from Multi-Resolution Radio-to-IR SED Fitting*

I will present ALMA band 6 data of a sample of 20 high redshift radio galaxies at 1<z<4. These new observations have a spatial resolution of 0.3" and rms level of 50 uJy, meaning that we start spatially resolving the 1.2mm emission. This allows us to complement the FIR data from Herschel and pinpoint the origin of the FIR emission.

We find a mixed picture of multiple components detected in ALMA, emission coming from regions far outside the host galaxy and very constraining non-detections. Also, for a few sources we have synchrotron emission from the radio lobes contaminating the ALMA observations.

To properly determine SFR, IR luminosities of the starburst and AGN as well as to disentangle the synchrotron contamination we have developed a new SED fitting routine. This code is able to handle multiple components in the bands where you have sub-arcsec resolution where you resolve individual components and simultaneously fits the combined models to the data points where the beam is too large to resolve individual components.

We find that the SFR is 5 times lower than previously estimated from single dish measurements with 2 orders of magnitude worse spatial resolution. We also find that several of the galaxies seem to be quenched and below the galaxy main sequence. This means that the host galaxies in our sample have over massive black holes and insufficient SFR to catching up with their back hole mass and that these objects might not end up at the local back hole mass-stellar bulge relation, or they need to increase their stellar mass in order to end up at the relation. This could maybe be though mergers or that the negative feedback from the AGN stops or becomes positive instead at some point during the evolution.

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**Fuyan Bian**

*Massive Galaxy Formation: What Can We Learn from the Most Luminous Lyman Break Galaxies at Redshift of z=3*

I present a survey of most luminous Lyman Break galaxies (LBGs) at z~3 in the NOAO Bootes field. This new survey cover an area an order of magnitude larger than any of previous deep field survey,

allowing us, for the first time, to reveal a population of the most luminous LBGs at z~3. With L> 5L* and star formation rate (SFR) ~500 M/yr, these spectroscopically-confirmed LBGs are some of the rarest and most intensive star forming systems in the early Universe. The fellow-up deep spectroscopic observations, Spitzer and HST observations have revealed the physical their properties, placed these newly discovered galaxies in the context of galaxy rapid growth through merger and cold flow accretion at the peak era of cosmic star formation, and provided a unique laboratory for massive galaxy formation theory.

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**William Pearson**
SRON

*The Main Sequence of Star Forming Galaxies beyond Herschel's Confusion Limit*

Herschel far infrared (FIR) deep cosmological surveys are known to suffer from source confusion and blending. Infrared (IR) emission provides information on star formation rates (SFRs) via thermal dust emission, which peaks in the FIR. Thus, to gain the best constraints on the IR emission, and hence the SFR, it is necessary to de-blend the deep Herschel images. A recent de-blending tool is XID+, which uses a Bayesian approach to extract flux densities for all objects in a prior source list. We have modified XID+ to introduce a Gaussian prior for each object, derived from the fitting of multi-wavelength data to spectral energy distributions. The result is a statistically more reliable extracted flux density for each object and hence a more reliable IR luminosity and SFR. We use these results to examine the main sequence of star forming galaxies (MS), a tight correlation between the SFR and stellar mass, from z = 0 to 6 in the COSMOS field. This allows us to trace how the MS has evolved over this period and link the high redshift, star-forming universe with the local universe. This presentation briefly introduces the new XID+ prior along with a deeper look at the results of the examination of the MS.

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**O. Ivy Wong**
ICRAR/UWA

*Radio Galaxy Zoo: First Data Release*

Radio Galaxy Zoo is an online citizen science project that enlists the help of the public to cross-match radio sources with infrared images of potential host galaxies. We present Radio Galaxy Zoo's first data release from the first 2.5 years of operation. Specifically, this first data release is based on cross-matches of radio sources from the FIRST survey and infrared host galaxies from the WISE survey. This data release consists of classifications for more than 70,000 FIRST radio source components where the consensus fraction amongst classifiers is greater or equal to 0.65. We find that these classifications are reliable at the 80% level or greater.

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## Session V: Galaxy Clusters III

## Session Chair: Anna Zovaro

**Marvin Blank**
New York University Abu Dhabi

*The NIHAO Project: High Resolution Simulations of Galaxy Formation and Evolution*

I will introduce the NIHAO project (Numerical Investigation of a Hundred Astrophysical Objects), a set of 100 cosmological high resolution zoom-in simulations of galaxies, whose halos range from dwarf to Milky Way masses. I will present ongoing and future projects that are based on the NIHAO simulations, including our current work to include black hole formation, accretion and feedback into our simulations and to extend their mass range from Milky Way to elliptical masses.

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**Sukyoung Yi**
Yonsei University

*Zoom-in Hydrodynamic Simulations of Clusters and Galaxy Evolution*

We have performed zoom-in simulations on 16 clusters of M200=13.5-15.0 extracted from a cosmological volume of 200Mpc on a side. We used the Ramses code equipped with the latest physics prescriptions. This is an effective way of building massive (Coma-like) clusters with high resolution which are generally not present in typical (100Mpc on a side) volume simulations. I present the highlights of the results from our first investigations. (1) Galaxy spin down is a universal phenomenon inside and outside clusters and non-merger related environmental effects play a significant role in galaxy spin down. (2) Phase-space analysis can be used to quantitatively and statistically determine the infall time of cluster galaxies and the amount of their mass loss before and after infall. (3) The pattern of dark matter and stellar stripping inside clusters has been found. (4) Gas stripping is also monitored and its impact on the star formation quenching and ICL enrichment are demonstrated. This presentation will be based on 3 papers published and one paper in preparation.

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**Fulai Guo**
Shanghai Astronomical Observatory

*Reversing Cooling Flows with AGN-Driven Shock Waves*

An important topic on galaxy groups and clusters is the well-known cooling flow problem, which has been investigated extensively in the past decade. Chandra observations have detected numerous X-ray deficient cavities in galaxy clusters, which are apparently evolved from the interaction of AGN jets with the ICM. While it is widely accepted that AGN jet feedback plays a key role in suppressing cooling flows, it is often debated on the detailed mechanism by which AGN jets deliver energy to the ICM. Here I will present our recent hydrodynamical simulations that aim to answer this important question and to investigate how AGN feedback suppresses cooling flows, with a focus on the roles of AGN-driven shock waves.

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**Andra Stroe**
ESO

*Cosmic Tsunamis and Tornadoes*

Red weather alert: dangerous cosmic weather forecast, in light of galaxy cluster mergers! Clusters grow through mergers with other clusters, events which give rise to the largest cosmic shock waves, as well as turbulence. Shocks travel like giant tsunamis through the cluster galaxies and the electron plasma between them, while turbulence stirs the intra-cluster medium. By bringing together optical, radio and HI data to probe past, present and future star formation, I will discuss how merger shocks and turbulence shape the evolution of cluster galaxies and reverse typical environmental trends. I will highlight how shock-induced star formation may a fundamental driver not only in the evolution of low-z clusters, but also in the context of proto-clusters and high-redshift clusters, where mergers and shocks were far more common than in the nearby Universe.

## Session VI: High Redshift Universe III

## Session Chair: Scott Croom

**Natasha Hurley-Walker**
Curtin University / International Centre for Radio Astronomy Research

*GLEAM: Exploring the Births and Deaths of AGN*

The GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey low-frequency catalogue of radio galaxies has just been published, and offers a new and exciting window into AGN at the extreme ends of their lives, and into the environments surrounding their jet-fed lobes. The wide bandwidth of GLEAM reveals a host of new compact low-frequency-turnover sources, where nascent AGN emission is confined by dense surrounding material. GLEAM's unprecedented high surface brightness sensitivity reveals ancient, diffuse radio-emitting lobes from long-dead AGN. I will discuss some of the published and upcoming results in this field from GLEAM, and briefly highlight the science potential of the even deeper survey to be performed with the expanded MWA.

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**Nicole Nesvadba (invited review)**
Institut d'Astrophysique Spatiale

*AGN Fuelling and Feedback in the Early Universe -- What do we Really Know?*

Nearly 20 years after Joe Silk and Martin Rees proposed that the immense accretion energy released by powerful AGN was sufficient to balance the baryon overcooling inherent to our Lambda-CDM model of cosmic structure formation, AGN feedback has become one of the central elements of our understanding of how baryons cool to form galaxies. A casual visitor of most conferences on the topic would probably leave with the impression that it is essentially a done deal that 'AGN behave like they should': They deposit fractions of their energy output into the ambient gas of their host galaxy, trigger enormous winds, and thereby drive and maintain a feedback cycle which effectively limits the growth of the black hole itself, as well as that of the galaxy (and even galaxy cluster) around it. But are we *really* there yet? I believe it is time for a critical review of our AGN-host-galaxy connection narrative, and in the review part of my talk, I will try to make a small contribution to this discussion, by highlighting a few elements that could shaken this view up just by a little bit, in particular from a high-z perspective. Following that, I will illustrate on the example of imaging spectroscopy of high-redshift radio-quiet and radio-loud AGN where we actually stand today in demonstrating the power of AGN feedback in shaping the early evolution of galaxies in the high-redshift Universe.

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**Jonathan Rogers**
University of Tasmania

*Energetics of Radio-Loud AGN from Multi-Wavelength Surveys*

Powerful jets associated with radio Active Galactic Nuclei (AGN) suppress star formation in galaxies through the heating and uplifting of dense central gas. The energetics of the radio AGN need to be quantified to characterise these feedback processes, for example by using analytical radio source models. However, the accurate conversion from observables to energetics in such techniques

requires a robust measurement of the source size, which is not well-defined for core-dominated sources.

I will present an alternative approach of fitting models to data in visibility space. Using the RAiSE dynamical radio source model (Turner & Shabala 2015), which has been developed to robustly characterise radio AGN in different environments, I will outline the modelling procedure, and present first AGN energetics results from the GAMA Legacy ATCA Southern Survey (GLASS) program.

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**Theresa Falkendal**
ESO

*ALMA Reveals Large Scale [CI] Emission around a High Redshift Radio Galaxy*

I will present a spectacular [CI](1-0) halo discovered with ALMA, surrounding the z=3.6 radio galaxy 4C19.71. This fine-structure line is a powerful H2 tracer, and arguably even better than the low-J CO lines as [CI] is not affected by cosmic ray destruction and is less sensitive to metallicity effects. We find that [CI] emission spread out over scales of 130 kpc. Intriguingly, the [CI] emission avoids the radio hotspots, but is strong in the direction extending beyond the radio jets. We discuss whether this suggests that that the jets expand in a previously dense direction which could strengthen the radio emission itself.

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**Darshan Kakkad**
European Southern Observatory-Garching

*Ionized and Molecular Gas Studies to Unveil AGN Feedback at High Redshift*

AGN feedback is often invoked in simulations to reproduce observed properties such as the massive end of galaxy mass functions. While efforts have been underway during the past decade to unveil the feedback effects at both low and high redshift, a direct observational evidence is still elusive in literature. I will present our current efforts on this front for high redshift galaxies using optical and near infrared IFU, single slit and sub-mm spectroscopic observations with WiFeS, SINFONI/VLT, XSHOOTER/VLT, and ALMA. Such a diverse set of high quality multiwavelength dataset sets the stage to understand how AGN affects the ionized as well as molecular gas content of the host galaxy. Some of the key questions addressed by this talk are: Are ionized outflows in high redshift galaxies driven by AGNs or star formation? What are the level of uncertainties in these outflow models and how to reduce them? Are such AGN outflows capable of affecting the molecular gas content in the host galaxy?

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**Ross Turner**
University of Tasmania

*Radio Galaxies as Standard Candles*

Immensely bright quasars and radio-loud active galactic nuclei (AGN) provide an opportunity to construct standard candles detectable to very high ($z > 4$) redshifts. We present a new technique for creating standardisable candles from radio observations of the very large synchrotron-emitting lobes inflated by powerful AGN radio jets; specifically our method uses radio flux, lobe angular size, and the radio SED spectral index and break frequency of classical double radio galaxies. This technique is

used to measure the distance to radio sources in the 3C and HeRGE surveys, providing redshift coverage from z = 0.05 to 4.5, and enabling us to tightly constrain the matter and dark energy densities. We further show that our distance measure provides reliable photometric redshifts for radio AGN based exclusively on multi-frequency radio observations. This technique may provide an alternative redshift measurement for radio surveys with limited optical spectroscopy.

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**Yuxiang Qin**
The University of Melbourne

*DRAGONS: The Small Contribution of Quasars to Reionization*

In this talk, I will present the result from an update of the Mutch et al. (2015) semi-analytic model, which tracks the growth of central supermassive black holes. I will investigate the contribution of quasars to reionization. The model is calibrated against the observed stellar mass function at $z\sim0.6-7$, the black hole mass function at $z\sim0.5$, the global ionizing emissivity at $z\sim2-5$, and the Thomson scattering optical depth. The model reproduces a Magorrian relation in agreement with observations at $z<0.5$, and predicts a decreasing black hole mass towards higher redshifts at given stellar mass. With the implementation of an opening angle for quasar radiation, which corresponds to an observable fraction of $\sim$23.4 per cent due to obscuration by dust, the model is able to reproduce the observed quasar luminosity function at $z\sim0.6-6$. At high redshift, the model is consistent with the bright end quasar luminosity function and suggests that the recent observation by Giallongo et al. (2015) at the faint end includes a fraction of stellar light and consequently overestimates the number of ionizing photons produced by quasars by a factor of 2 at $z\sim5$. When we include quasars in reionization calculations using 21cmFAST, we do not find a significant contribution.

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## Session VII: High Redshift Universe IV

## Session Chair: Dipanjan Mukherjee

**Lilian Garratt-Smithson**
Leicester University

*Slow and Steady to Win the Race? High Mass X-Ray Binary Feedback in Low-Mass Galaxies*

During galaxy formation the complex interplay of stellar processes is difficult to unravel, particularly in low-mass galaxies where the various timescales (eg. dynamical, cooling, star formation, stellar evolution, SNe and feedback) may be comparable. The efficiency of stellar feedback in moderating star formation (eg. via gaseous outflows) is governed by the amount of energy deposited into the interstellar medium, as well as the structure and temperature of the ambient gas. Our work looks at the interplay between SNe feedback and High Mass X-ray Binary (HMXB) feedback and their resultant effects on galactic evolution – focussing on low-mass (<10^9 solar mass) galaxies at high redshift. In particular we look at feedback from the relativistic jets produced by wind-fed accretion onto the neutron star/black hole within a HMXB system. The gradual heating from HMXBs has the potential to globally affect the star formation efficiency and rate of a galaxy. HMXBs could also account, in part, for the variety of star formation histories seen in dwarf galaxies.

We use the smoothed particle hydrodynamics code GADGET-3 to conduct very high resolution simulations (~1 solar mass per gas particle) of the ambient gas and both types of feedback, using a physically motivated implementation of the gradual heating from HMXBs. Initially, we investigate the effect of a HMXB population (through stellar winds, SNe and HMXB feedback) on the star formation efficiency of a Giant Molecular Cloud at a range of metallicities. Secondly, we look at the global effect of a HMXB population on the gaseous outflows of an isolated dwarf galaxy at high redshift. Through our work we hope to understand the importance of the inclusion of HMXB feedback in feedback prescriptions for cosmological simulations of galaxy formation.

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**Christian Wolf**
Australian National University

*The Growth of Supermassive Black Holes 1 Gyr after the Big Bang*

Giant black holes at the centres of galaxies reach masses over ten billion times that of our Sun. Surprisingly, these are found already 1 Gyr after the Big Bang. How they grew to such mass is a profound puzzle for physics. Did they grow at vastly super-Eddington rates or form in new ways not predicted currently? Here I will present the work we pursue with SkyMapper, Taipan and other facilities to measure the time evolution of the black-hole mass function in the epoch from 750 to 1,350 million years after the Big Bang, which should differentiate between the above two scenarios.

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**Guillaume Drouart**
Curtin University

*AGN Evolution from the Radio SED of High-Z Powerful Radio Galaxies*

The SKA_LOW pathfinder MWA (Murchison Wide Array) released the first all-sky radio survey, GLEAM, in the 80-230MHz range, revealing more than 0.3 million extragalactic sources. Combined with data up to 20GHz, we build exquisite radio SEDs (>~30 data-points) of a sample of a well-known

sample of 70 high redshift radio galaxies (the HeRGE sample: L_3GHz restframe > 10^26 W/Hz and z>1). The strong radio emission of these sources betrays powerful jets ramming against the intergalactic medium and potentially injecting a lot of energy back into the direct vicinity of the galaxy host. Combined with our previous multi-wavelength campaign from optical to submm (including VLT, Keck, HST, Spitzer, Herschel, SCUBA, LABOCA, and more recently ALMA), we now start building a complete picture on the total energy (re-)distribution of these systems and their different components believed to the progenitors of our local massive galaxies. I will present our most recent results from our radio SED fitting and discuss the connection with our previous results in term of radio loud AGN evolution at the peak of activity in the Universe.

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**Rajan Chhetri**
Curtin University/CAASTRO

*Properties of Sub Arcsecond Compact Source Population Identified Using Wide Field Interplanetary Scintillation with The MWA*

Recently, low radio frequency wide field-of-view instruments have opened up new opportunities to investigate radio galaxies and their evolution. However, their sub arcsecond compact cores still elude investigations owing to the limitations of angular resolutions of these instruments. With our recently developed technique combining interplanetary scintillation with the wide field-of-view of the Murchison Widefield Array, we overcome this challenge to identify sub arcsecond compact components in large numbers from low radio frequencies. In this presentation, I will outline the technique and present radio properties of compact active galactic nuclei selected from 162 MHz. I will also present results on the differences in gamma ray properties of these low radio frequency compact objects compared against their counterparts from high radio frequencies. I also aim to outline the implications of this work for future instrument the SKA-Low.

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## Session VIII: Low Redshift Universe I

## Session Chair: Enrico di Teodoro

**Sugata Kaviraj (invited review)**

*The Triggering of AGN in the Local Universe and their Role in Shaping Galaxy Evolution*

I discuss the processes that are responsible for triggering AGN in the low redshift Universe, the impact that these AGN are likely to have on their host galaxies and whether the interplay between AGN and their host galaxies may evolve with redshift. I review the recent literature, which suggests an important role for interactions in triggering all modes of AGN, in all environments. However, studies also show that in groups and the field, where the gas that triggers star formation and AGN activity is brought in via accretion and mergers, the triggering of AGN is delayed by several dynamical timescales compared to the peak of the star formation activity. This reduces the ability of the AGN to regulate the star formation episode, potentially reducing the impact of AGN feedback to mopping up residual (or recycled) gas in the system. If AGN are significant in influencing stellar mass growth over cosmic time, a qualitatively different interplay between AGN and star formation activity must be in place around the peak epoch of cosmic star formation.

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**Anna Ferre-Mateu**
Swinburne University of Technology

*SMBHs Coevolution Challenged by nearby Fossil Red Nuggets*

It has been long assumed that SMBHs form and evolve hand by hand with their galaxy host. However, a sample of nearby massive compact galaxies, fossil relics of the high-z massive population, are telling us a different history (Ferré-Mateu et al. 2015, 2017). These local red nuggets, massive compact galaxies without merging accretion since z~2, seem to have a set of very thrilling properties. One of them is that they all host seemingly übermassive SMBHs. This makes them extreme outliers in the SMBH-galaxy local scaling relations, challenging their assumed universal co-evolution.

In this talk, I will show that this is due to the uncommon evolutionary path followed by these relic galaxies. Instead of following the two-phase growth channel expected for massive galaxies, they remain structurally untouched by skipping the second phase after z~2, while the SMBHs is already in place. I will show that if the outliers had followed the normal evolutionary path by growing in size (and slightly in mass) via merger activity, the expected growth in mass would place them closer to the observed local relations. Finally, I will show that there is a strong dependence with galaxy mass, which changes the nature of such deviations. The relic scenario prevails for massive galaxies, but as we go to less massive ones, stripping of the galaxy mass becomes the relevant process that places them outside the scaling relations.

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**Meiert Grootes**
ESA/ESTEC

*The Baryon Cycle and its (lack of) Environmental Dependencies*

The cycle of gas into and out of galaxies, fuelling the conversion of gas into stars, is fundamental to the evolution of galaxies. Indeed, the paradigm that this baryon cycle is self-regulated has proven to

be successful at explaining a number of trends, foremost amongst which is the main sequence of star forming galaxies (MS). Combined with a halo mass dependence of the inflow rate and environmental quenching of satellite galaxies, this paradigm represents a compellingly simple picture of galaxy evolution.

We use the current SFRs of morphologically selected samples of disk galaxies drawn from the GAMA survey to test this paradigm in the local universe ($z<0.13$). We find support for the paradigm of gradually evolving self-regulated balance in the baryon cycle of galaxies in the SFR - M* relation of non-group disk galaxies, which we demonstrate evolves smoothly even over a redshift baseline of $dz=0.1$. Surprisingly, however, the SFR - M* of non-grouped and group central disk galaxies coincide, evidencing a lack of halo mass dependence even on the mass scale of group halos, and leading to a degree of tension with the picture of a simple self-regulated balance for group central galaxies. This lack of environmental dependence is only exacerbated by the fact that the gas-fuelling of the majority of disk dominated satellite group galaxies is nigh identical to that of their group central and non-grouped counterparts, high-lighting a pronounced lack of dependence of the baryon-cycle on the environment and on halo mass in particular.

Finally, we empirically quantify the group-wide impact of an AGN in the group central galaxy on the star-formation of galaxies in galaxy groups as a new and potentially significant environmental influence.

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**Sanchayeeta Borthakur**
Johns Hopkins University

*What Does the Circumgalactic Medium Tell Us about the Galaxy Colour Dichotomy*

Galaxies constantly exchange matter and energy with their surroundings. Galaxy growth and subsequent star formation is maintained by accretion of gas. In turn, young stars produce vast amounts of energy that may ionize gas in the cosmic web as well as spew out metals in the intergalactic medium (IGM). I will discuss the advances we have made in understanding the physics behind baryon flows by studying the properties of the circumgalactic medium (CGM). I will present observational evidence that suggests of the first indications of the pathways via which galaxies acquire gas and feed their disks.

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**Sarah White**
ICRAR/Curtin University

*The MWA GLEAM 4-Jy Sample*

The GaLactic and Extragalactic All-sky MWA (GLEAM) survey is a continuum survey conducted using the Murchison Widefield Array (MWA). The first catalogue from this survey contains around 300,000 extragalactic sources, each with 20 radio flux-densities spanning a frequency range of 72-231 MHz. I will present the MWA GLEAM 4-Jy Sample, which consists of around 1,850 sources brighter than 4 Jy at 151 MHz. The sample is a factor 10 times larger than the most prominent low-frequency radio-source sample that is optically complete: the revised Third Cambridge Catalogue of Radio Sources (3CRR). As a result, the properties of powerful active galactic nuclei (AGN) and strongly-starbursting systems can be studied more robustly. Several of the sources have extended radio emission, and follow-up data from the Australia Telescope Compact Array (ATCA) enables us to extend our radio spectra to higher frequencies than those of the MWA. As a result, we can investigate whether there is evidence of a spectral turnover, indicative of synchrotron self-absorption or free-free absorption

due to the presence of neutral gas. Furthermore, we use multi-wavelength data over the Southern hemisphere - such as existing optical spectra from the 6-degree Field Galaxy Survey (6dFGS) and mid-infrared images from the Widefield Infrared Survey Explorer (WISE) - to identify the host galaxies of the low-frequency radio emission. Those with 6dFGS spectra are then used to provide first insights into the local sources with optically-bright hosts (median z = 0.088).

**Session IX: Low Redshift II**

**Session Chair: William Pearson**

**Julie Banfield**
Australian National University

*Shaping the Circumgalactic Medium through Radio-Loud AGN Interactions on KPC Scales*

Though the radio-mode feedback from active galactic nuclei (AGN) has been identified as a likely source of feedback in high mass galaxy formation, few such systems have been directly observed. As the radio-loud AGN jets break through the host galaxy, they can help to remove gas from the system or heat the gas up, thus helping to prevent or quench star formation. At the same time the radio-loud AGN jets can affect the circumgalactic medium and the nearby galaxies as they expand away from the host galaxy. Radio-loud AGN can be used to study AGN feedback due to the amount of energy the radio jets deposit in their surrounding environment. I present the recent results of a population of radio-loud AGN with their host galaxies revealing strong [OIII]5007 and optical morphologies more akin to late-type disks rather than early-type spheroids. Additionally, 50 per cent of these host galaxies of the radio-loud AGN show clear evidence of Ha outflows driven-off the galaxy disk by the AGN activity. The radio structure of the AGN show a number of morphologies including x-shaped radio emission where the radio-loud jets are interacting with the gas reservoirs of the cirumgalactic medium at kpc scales. I will present evidence that these radio-loud AGN may be the cousins of the radio-jet and molecular gas interaction found in Minkowski's Object, 3C 285, 4C 41.17, and Centaurus A.

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**Elizabeth Mahony**
University of Sydney

*Jet-Driven Outflows of Cold Gas: The Case of 3C293*

While it is generally accepted that the evolution of galaxies and their central SMBH are strongly linked, the feedback mechanisms responsible for this are less clear. Outflows are often thought to be driven by quasar-driven winds or massive starbursts, but recent results have shown that in some cases radio jets could be responsible for driving fast outflows of gas. In this talk I will present recent results on jet-driven outflows of gas in the nearby radio galaxy 3C293. Using JVLA radio observations and recent IFU observations we detect fast outflows (~1200 km/s) being driven by the radio-jet approximately 0.5 kpc from the central core of the AGN. Pinpointing the location of these outflows enables us to derive crucial parameters, such as the mass outflow rates and kinetic energy involved, which can then be compared to feedback predictions from galaxy evolution simulations.

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**Philip Taylor**
Australian National University

*Galaxies Growing Old: the Transition to Quiescence at 3x10^10 Solar Masses*

I will present results of a cosmological simulation that includes star formation and feedback, chemical evolution, and supermassive black holes. By fitting a simple function of stellar mass, gas mass, black hole mass, and environment to the star formation rate (SFR) of galaxies, I will show that SFR is primarily determined by the gas content of a galaxy, and is much less dependent on the stellar

mass than suggested by the star forming main sequence. I will also show that feedback from black holes becomes important once they have grown to ~2x10^7 solar masses, corresponding to a stellar mass of ~3x10^10 solar masses, in agreement with observations (eg, Kauffmann 2003).

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**Stas Shabala**
University of Tasmania

*Fundamentally Confused? Nature, Nurture and Radio Galaxy Scaling Relations*

The so-called Fundamental Plane (FP) of black hole activity relates observable jet properties (measured via radio synchrotron emission) to those of the black hole (namely mass and dimensionless accretion rate). The FP correlations hold for supermassive and Galactic black holes, and provide important insights into accretion and outflow physics.

Focusing on scaling relations in supermassive black holes, I use SDSS, FIRST and NVSS data together with dynamical models of radio AGN to show that much of the observed low-redshift FP is due to two mechanisms: (1) existence of different scaling relations for high and low accretion rate states; and (2) the role of large-scale (tens to hundreds of kpc) environment in determining both the accretion mode and strength of observed lobe synchrotron emission. In this picture, the black hole mass dependence is best understood as a proxy for environment. A specific prediction of the models is that current surveys systematically underestimate radio emission associated with AGN in poor environments, due to insufficient surface brightness sensitivity. The observed slope and normalisation of the FP therefore depend on both the sample demographics and observing strategy.

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**Lucia Armillotta**
ANU- RSAA

*The Physics of the Disc-Corona Interface: How Feedback Regulates Accretion and Quenching*

In star-forming galaxies, stellar feedback can have a dual effect on the external environment both suppressing and stimulating gas accretion. The trigger of gas accretion can be caused by disc material ejected into the halo by galactic fountain and its interaction with the surrounding hot corona. Indeed, the mixing between the cold/metal-rich disc gas and the hot gas can dramatically reduce the cooling time of a portion of the corona and produce its condensation and accretion. This fresh gas becomes then available for the star formation of the galaxy.

We studied the disc-corona interface in galaxies with very different halo (virial) masses with high-resolution 2D/3D hydrodynamical simulations including radiative cooling and thermal conduction. Our simulations show that the amount of coronal condensation strongly depends on the environment as it becomes less efficient for increasing coronal temperature. Thus, the ability of galactic fountains to cool the corona decreases going from late-type to early-type disc galaxies leading to the switching off of accretion and having potential implications for the quenching of star formation in systems with virial mass larger than 10^13 Msun.

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**Session X: Low Redshift III**

**Session Chair: Lauranne Lanz**

**Christian Wolf**
Australian National University

*SkyMapper*

The SkyMapper Southern Survey has released its first all-Southern sky dataset in June 2017. This talk describes how SkyMapper data will be useful for the analysis of nearby galaxies, the environment of low-redshift galaxies as well as quasars across a range of redshifts. I will show images, describe the data access to DR1 and give an outlook to further releases.

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**Katey Alatalo (invited review)**
Carnegie Observatories

*Shining Light on the Pathways of Galaxy Transformation*

Modern day galaxies populate a bimodal distribution, in both morphology and color space. Their morphological and color properties are also inter-related, with lenticular and elliptical galaxies usually exhibiting red colors and spiral galaxies usually exhibiting blue colors. In color space, there is a genuine dearth of intermediate colored galaxies, suggesting that the transition a galaxy undergoes to transform must be rapid, and quenching galaxies, rare. Gas - its presence, absence, and mechanics - serves as the anchor of a galaxy's transformation from blue to red. I will discuss the nature of gas in transitioning and transitioned galaxies through two lenses: (1) How a galaxy transition is able to impact the behavior of molecular gas, and (2) how new observations of molecular gas in quenching and quenched galaxies has recast our understanding of how they ultimately metamorphose from blue, star-forming spirals into red, quiescent ellipticals and lenticulars.

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**Angel Lopez-Sanchez**
Australian Astronomical Observatory and Macquarie University

*The Neutral Gas Content of the CALIFA Galaxies*

The CALIFA (Calar Alto Legacy Integral Field Area, Sánchez et al. 2012; 2016) survey has obtained spatially resolved spectroscopy data for ~700 galaxies in the Local Universe. Using integral field spectroscopy (IFS), CALIFA provides details about the stellar populations, the star-formation activity, the kinematics, and the metal content (among other properties) within nearby galaxies.

We derive the total neutral gas mass of the CALIFA galaxies using available measurements of the 21 cm HI line reported in the literature. We examine the relations of the neutral gas content with those properties derived from IFS data, particularly stellar mass, star-formation rate (SFR) and metallicity (oxygen abundance). Our study, that follows a Principal Component Analysis (PCA), suggests that the scatter in the mass-metallicity relation are better understood by the amount of neutral gas in these galaxies instead of the SFR, as proposed using single-fibre spectroscopic surveys. Our analysis also seems to show signatures of gas accretion happening in some of galaxies.

We will define the Baryonic Fundamental Plane for star-forming galaxies in the space formed by stellar mass, oxygen abundance (as proxy of metallicity) and the gas-to-star mass ratio. This

relationship has been recently predicted by cosmological hydro-dynamical simulations. We will discuss the implications of such Baryonic Fundamental Plane in the context of galaxy evolution and its role in the on-going and future large galaxy surveys.

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**Scott Croom**
University of Sydney

*Resolving Environmental Quenching of Star Formation with SAMI*

Environment is one of the central drivers of galaxy evolution and we see many differences between galaxies in low density and high density environments. Several physical processes are at play, and the importance of each of them varies as we move across the hierarchy of structure, from voids, to groups, and then to massive galaxy clusters. We are using the SAMI Galaxy Survey to identify the physical mechanisms for environmental quenching of star formation. We find that galaxies in high mass groups (halo mass log(M)>12.5, selected from the GAMA Survey) show evidence of star formation preferentially being shut down in their outer parts. In contrast, galaxies in lower mass groups can show enhanced central star formation. Surprisingly, these signatures are most evident in high mass galaxies (stellar mass log(M)>10), suggesting different pathways or time-scales for the environmental transitions of low and high mass galaxies. We combine our spatially resolved star formation measurements with kinematics and stellar population ages to infer the physical processes that are work in these galaxies, and so shed light on the mechanisms behind environmental transitions.

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**Adam Thomas**
Australian National University

*Spatially-Resolved Measurements of Narrow Line Region and HII Region Abundances in an Active Galaxy*

We present a code providing a new and general way to compare measured emission-line fluxes with photoionisation model grids, NebulaBayes, and demonstrate applications of the code. Any parameter of a model grid may be constrained, and in particular we are interested in the metallicity, which is routinely measured in HII regions using optical line fluxes, but not in AGN narrow-line regions (NLRs). Optical IFU data for the galaxy MCG-02-51-008 from the Siding Spring Southern Seyfert Spectroscopic Snapshot Survey (S7) is used in a case study. We measure a metallicity gradient in both the star-forming disk (using an HII region grid) and in an extended narrow line region (ENLR) 'ionisation cone' (using a NLR grid). We have additionally applied NebulaBayes to data across the S7 sample to measure the nuclear metallicity of a large sample of local Seyfert galaxies. Routine measurements of ENLR metallicity hold potential for building our understanding of AGN feedback on the host galaxy.

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**Darshan Kakkad**
European Southern Observatory-Garching

*Spatially Resolved Electron Density and ISM Conditions in Low-Redshift AGNs*

The Narrow Line Region of the AGN host galaxies are an important tool to investigate the impact of AGN and star formation on the surrounding ISM. Physical quantities such as electron density and temperature are useful in determining quantities such as the ISM chemical abundances and mass outflow rates, which suffer through a huge uncertainty due to unconstrained density values in the NLR. The Siding Spring Southern Seyfert Spectroscopic Snapshot Survey (S7) probes the ionization conditions in the extended-narrow Line regions of the nearby AGN host galaxies and is ideal to do spatially resolved studies of ionized gas. In this talk, I will present one of the first attempts to map electron density in the NLR for a statistical sample of nearby AGN host galaxies using the S7 survey. The study reveals a wide diversity in the density structures in different galaxies with significantly high density values in targets showing active AGN driven outflows. I will discuss the implications of this study on the existing outflow models and the ISM conditions of high redshift galaxies.

**Session XI: Low Redshift IV**

**Session Chair: Jonathan Rogers**

**Dan Taranu**
ICRAR/UWA

*Feedback and the Structure of Local Galaxies: Insights from Simulations and Integral Field Kinematics*

The physical and structural parameters of galaxies - including mass, sizes, angular momentum and bulge fraction - show several strong and morphology-dependent correlations. In turn, these correlations place strong constraints on the physics of galaxy formation, especially feedback. I will discuss recent projects to make robust measurements of these parameters using resolved stellar kinematics from the SAMI galaxy survey (with ancillary deep imaging and HI spectra) and compare them to predictions from simulations with novel implementations of supernova (Keller+15) and black hole feedback (Romulus, Tremmel+17). While simulations have had some success producing disk-like galaxies with appropriate stellar masses given their host halos, matching the detailed structure of galaxies (sizes, bulge fractions and disk thicknesses) remains a challenge, especially at the low-mass end. I will end by discussing how controlled simulations of isolated disks and mergers can help to identify how and where feedback succeeds or fails to regulate galaxy growth.

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**Sarah White**
ICRAR/Curtin University

*Accretion and Star Formation in 'Radio-Quiet' Quasars*

Studying the interplay of accretion and star formation is crucial to our understanding of galaxy evolution. As we probe low radio luminosities, the two main populations are star-forming galaxies and radio-quiet quasars (RQQs). How RQQs contribute to the total radio emission is under debate, with previous studies arguing that their star formation dominates. In this talk I will demonstrate the importance of accretion-related radio emission in RQQs. Our sample of quasars are all at $z\sim1$, thereby minimising evolutionary effects, and have been selected to span a factor of $\sim$100 in optical luminosity, so that the luminosity dependence of their properties can be studied. We have imaged the sample using the Karl G. Jansky Very Large Array (JVLA), whose high sensitivity results in 35 RQQs being detected above 2 σ at 1.5 GHz. This radio dataset is combined with far-infrared luminosities derived from grey-body fitting to Herschel photometry. By exploiting the far-infrared–radio correlation observed for star-forming galaxies, and comparing two independent estimates of the star-formation rate, we show that star formation alone is not sufficient to explain the total radio emission. Considering RQQs above a 2-σ detection level in both the radio and the far-infrared, 92% are accretion-dominated, and the accretion process accounts for 80% of the radio luminosity when summed across the objects. The radio emission connected with accretion appears to be correlated with the optical luminosity of the RQQ, whilst a weaker luminosity-dependence is evident for the radio emission connected with star formation.

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**Jesse Swan**
University of Tasmania

*Cosmic Evolution of Star Formation and AGN Activity as Probed by the Australia Telescope Large Area Survey (ATLAS)*

The third data release from the Australia Telescope Large Area Survey (ATLAS) provides access to deep 1.4 GHz observations. Over the total 6.3 deg^2 sky area of Chandra Deep Field South (CDFS), and European Large Area ISO Survey South 1 (ELAIS-S1), ATLAS reaches sensitivities of between 14 and 17μJy beam−1. Using Spitzer infrared detections as an intermediary, these 5118 5σ radio sources are robustly combined with over 1300 targeted spectroscopic redshifts obtained via the OzDES program; and a further 767 redshifts available from literature. With these data, we are probing radio luminosities down to 10^20.5 W/Hz at redshifts z < 0.8 to more broadly gauge the cosmic evolution of star formation and AGN activity in galaxies

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**Kevin Schawinski**
ETH Zurich

*A Universal Model for the AGN Phenomenon*

I present ongoing work on building a universal model for the AGN phenomenon. We forward model the luminosity and variability of AGN as they grow together with the galaxy population to give rise to the diverse phenomenology of Seyferts, quasars and radio galaxies. Using this forward modeling approach, we can constrain the physics driving black hole growth and the role black hole growth phases have in the evolution of galaxies. We find that the AGN phenomenon is largely insensitive to the particular features of their host galaxies, and is rather driven by physics near the AGN central engine, or even in the accretion disk itself. The only difference is the activity in blue and red galaxies, with some modification in the case of major mergers. I make the case that a full understanding of the AGN phenomenon requires consideration of the variability spectrum on all time scales, from seconds to the age of the universe.

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## Session XII: Centre of Galaxies I

## Session Chair: Tiffany Day

**Chris Power (invited review)**
ICRAR/UWA

*AGN Feeding and Feedback in Central Galaxies*

Feedback from super-massive black holes is now widely recognised to be fundamental in shaping the properties of higher mass galaxies. Galaxy formation models require AGN feedback to regulate the masses of the most massive galaxies, while scaling relations between SMBHs and their host galaxy properties seem to be most plausibly explained by powerful SMBH-driven outflows. I will review the modelling of AGN feeding and feedback to date, and what it implies for our understanding of galaxy evolution, and I will highlight what needs to be done in the coming years.

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**Martin Bourne**
Institute of Astronomy and Kavli Institute for Cosmology, University of Cambridge

*Simulation of Jets and Winds from Supermassive Black Holes*

Accretion onto supermassive black holes (SMBHs) releases large amounts of energy in a number of forms, including winds and jets. Such feedback can mould galaxy properties and mediate SMBH-host galaxy co-evolution. I will discuss simulations and numerical techniques used to understand these feedback processes and host galaxy - feedback interactions.

Accretion disc driven winds, such as the ultra-fast outflows observed in X-rays, carry sufficient energy to significantly impact the interstellar medium (ISM). Ultra-fast outflows have been invoked to explain observed scaling relations (e.g., M-sigma) and as the source of large-scale, massive outflows, with large momentum-boosts. An important issue is whether the winds are in the momentum or energy conserving regime, which has critical importance in understanding feedback coupling efficiency and hence the extent to which SMBH feedback plays a role in galaxy evolution. I will outline theoretically modelled, observational signatures of cooling wind shocks, which distinguish between momentum and energy conserving regimes. Additionally, I will present the outcomes of high-resolution, hydrodynamical simulations exploring how an energy-driven outflow interacts with the turbulent, multiphase ISM and how this affects the ability of AGN-driven winds to drive large-scale outflows. Importantly we find that the structure of the ISM makes galaxies far more resilient to feedback than one may expect based on simple analytical arguments.

Radio jets and the X-ray cavities they inflate are often observed in galaxy groups and clusters. Such feedback heats and stirs the intra-cluster medium (ICM) and influences galaxy and cluster evolution. Observations, such as those of the Perseus cluster, performed by the Hitomi satellite, have shed light on properties of the ICM and placed constraints on our understanding of jet-driven feedback in galaxy clusters. From a theoretical stand point, we have implemented a new jet feedback scheme into the moving mesh code AREPO in an effort to further improve our understanding of this topic. We have performed comparisons of jet injection techniques in order to understand how numerics can impact on jet evolution. Further, the simulations allow us to investigate the interplay between the jet, cocoon and ICM in both idealised and more realistic conditions. We study mechanisms that may heat the ICM with a particular emphasis placed upon the roles of both jet-driven turbulence and pre-existing large-scale bulk turbulence within the ICM.

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**Rainer Weinberger**
Heidelberg Institute for Theoretical Studies

*Supermassive Black Hole Feedback in the Next Generation Illustris Simulations*

It is generally believed that feedback from supermassive black holes has a significant impact on massive galaxies, galaxy groups and clusters. In this talk, I will present a new model for supermassive black hole growth and feedback in cosmological simulations, implemented in the AREPO code (Weinberger et al. 2017, MNRAS, 465, 3291). After presenting the main features of the model, I will show its impact in the next generation Illustris simulations. This major simulation project so far consists of two (~100Mpc and ~300Mpc) high-resolution cosmological volume, magnetohydrodynamical simulations. I will discuss how the new black hole implementation affects observables of massive galaxies and how this differs from the original Illustris simulation. This way, I will quantify the uncertainty in the modeling of the formation of massive galaxies due to AGN feedback implementations. Towards the end, I will give an outlook how future feedback models in cosmological simulations can be more predictive. I will present a high resolution study of AGN jets interacting with the surrounding intra-cluster medium and show how we can systematically use idealized, high resolution simulations to understand the small-scale feedback physics and to develop more predictive sub-resolution models for future simulation projects.

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**Renuka Pechetti**
University of Utah

*Enhanced Mass-to-Light Ratios in Low Mass Early Type Galaxies*

Kinematics of low mass early type galaxies (ETGs) are difficult to observe because of their low velocity dispersions near the center. This makes it difficult for us to find black holes in low mass galaxies. Due to this, there is a huge amount of scatter in M- σ relationship in the low mass end. Discovery of black holes in low mass galaxies is the key to understanding the evolution of black holes, if they grow from stellar mass black holes to supermassive black holes or if there is some other process involved.

I will present the detection of a statistically significant enhancement in the central mass-to-light ratios (M/L) of a sample of 28 low mass early type ATLAS3D galaxies that have a mass range $9.5<\log(M/M_{\odot})<10.5$. We exclude the galaxies with obvious dust emission and central color gradients. We use high resolution HST images to derive mass models for the galaxies in the central region and combine this with the central velocity dispersion values from ATLAS3D data to obtain best-fit central M/L. We show that the enhancement in central M/L can be best described by a black hole model and present the BH masses for these galaxies. We also constrain the scatter in M- σ relationship in the lower mass end based on Monte-Carlo simulations and data.

Finally, we present the simulations that show the possibility of these low mass ETGs acting as the progenitors for Ultra Compact dwarf galaxies (UCDs). This provides new insights into the theory that UCDs can be considered as tidally stripped remnants of low mass ETGs.

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**Dipanjan Mukherjee**
RSAA, ANU

*Relativistic Jet Feedback in Gas Disks*

Relativistic jets from AGNs are an important driver of feedback in galaxies. Interaction of such jets with an inhomogeneous ISM significantly affect the radio and optical morphology and the evolution of the galaxy. We shall present the results of our recent 3D relativistic hydrodynamic simulations probing the interaction of AGN jets with a gas disk on scales of a few kilo parsecs. The coupling of the jet with the turbulent gas is less strong than a spherically distributed ISM modelled before, as the jet breaks out with relative ease. However post break out, the high pressure bubble spreads over the disk compressing it. I will discuss the effect on the gas kinematics under the influence of such jets, the effect of jet orientation and its implications for the long term evolution of the turbulent gas. The multi-phase nature of the resultant ISM in our simulations provides an ideal test bed to compare with observed results. I will discuss how our simulations compare with observed results of jet-ISM interactions, such as in IC 5063.

## Session XIII: Centre of Galaxies II

## Session Chair: Rajan Chhetri

**Geoffrey Bicknell (invited)**
Australian National University

*Relativistic Jet Feedback in Evolving Galaxies*

Relativistic jets, initiated during a starburst phase of a galaxy inject a large amount of energy and momentum into the interstellar medium, which can have the effect of quenching star formation. We have suggested that Gigahertz Peak Spectrum (GPS) and Compact Steep Spectrum (CSS) radio galaxies represent an active phase of AGN feedback and our recent simulations show that the turnover in the radio spectrum and the low frequency spectral slope may be explained by free-free absorption by the inhomogeneous interstellar medium (ISM). Therefore, radio studies of GPS and CSS sources form a valuable complement to optical-IR observations in that they provide information on the structure and extent of the ISM. The duty cycle of these sources is also important for modelling of the star formation - feedback cycle.

This talk incorporates collaborative research with Dipanjan Mukherjee, Ralph Sutherland and Alex Wagner.

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**Robert Schulz**
ASTRON

*Jet-Driven HI Outflows in Radio Galaxies - A VLBI Perspective*

The jets of powerful radio galaxies are known to play a vital role in regulating the gas distribution of the host galaxy as they push through the interstellar medium. Evidence for this includes observations of fast outflows of neutral hydrogen gas detected in absorption in a number of radio galaxies, though these observations mostly lacked the resolution to pinpoint the location of the outflow with respect to the jet system. However, this can be achieved by Very Long Baseline Interferometry (VLBI) and it was demonstrated for the first time in 4C12.50. Based on this, we have been conducting a study to locate and characterise the outflow of neutral gas on parsec scales in a small sample of young and recently restarted radio galaxies. In one of our objects, the restarted giant radio galaxy 3C236, the improved sensitivity and bandwidth of our global VLBI experiment allowed us to locate at least part of the outflowing gas over a velocity range of about 600 km/s within about 40pc from the nuclear region. In addition, we find that the diffuse gas in the region of the counter-jet lobe is not just related to the regular rotating disk, but also contains an outflowing component. These clouds seem to trace the gas through which the jet is travelling, thus providing constrains on the physical conditions that could be important for theoretical models. We will discuss further results from this project which also serves as a pilot for a future larger sample study with which statistical analysis would be possible.

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**Anna Zovaro**
The Australian National University

*Catching Feedback in the Act at the Sub-Kpc Scale*

Powerful jets emerging from the black holes in active galactic nuclei (AGN) interact with the interstellar medium (ISM) as they leave the nucleus, dramatically influencing the evolution of the host galaxy. In particular, star formation is thought to be either enhanced (positive feedback) or suppressed (negative feedback) by this process. Simulations have shown that both positive and negative feedback processes may occur; however, the dominant feedback mechanism is influenced by both the precise structure of the ISM and the power of the jet, making it difficult to predict which mechanism will dominate, and in turn whether overall star formation is enhanced or suppressed. Gigahertz Peak Spectrum (GPS) and Compact Steep Spectrum (CSS) sources are young, relatively low-power radio sources with compact and often distorted morphologies resulting from the interaction of jets with a dense, inhomogeneous ISM. Potential progenitors to FR I & II radio sources, GPS/CSS sources are believed to be in an intermediate stage of evolution in which the jets have not yet broken free of the ISM and are actively suppressing or enhancing star formation. Spatially resolved observations of GPS and CSS sources on the kpc scale can therefore provide us with a valuable insight into these jet-ISM feedback processes. We present NIFS H- and K-band spatially-resolved integral field spectroscopy of the two radio sources 4C31.04 and 4C14.82. The morphology, structure and kinematics of the central gas has been analysed in conjunction with indicators of current and historical star formation to search for signatures of positive or negative feedback.

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**Michael Drinkwater**
University of Queensland

*Black Holes in both Normal and Disrupted Dwarf Galaxies*

Supermassive black holes play a crucial role in galaxy formation because the energy they emit can help regulate the formation of stars in their host galaxies. The properties of black holes in large galaxies are well understood, but recent work predicts that average black hole masses in dwarf galaxies have been overestimated by factors as large as one hundred. We are searching for black holes in a complete sample of dwarf galaxies in the Virgo Cluster to test this prediction. Our method uses high-resolution infra-red spectroscopy on the Keck and Gemini telescopes to directly measure the velocity fields at the centres of these small galaxies. We have observed three dwarf galaxies so far and all three contain supermassive black holes. Our detection provides a direct link between normal dwarf galaxies in the cluster and extremely small “ultra-compact dwarf” (UCD) galaxies thought to be formed by the disruption of normal galaxies -- because similar-sized black holes have also been found in UCDs.

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**Darren Croton**
Swinburne University of Technology

*The Many Lives of AGN II: The Formation and Evolution of Radio Jets and their Impact on Galaxy Evolution*

In this talk I describe new efforts to model radio AGN in a cosmological context using the SAGE semi-analytic galaxy model and a number of large cosmological N-body simulations. Our new method tracks the physical properties of radio jets in massive galaxies, including the evolution of radio lobes and their impact on the surrounding gas. Unlike the previous efforts of Croton et al. 2006, we now

self consistently track the cooling-heating cycle that significantly shapes the life and death of many types of galaxies. Adding jet physics to SAGE adds new physical properties to the model output, which in turn allows us to make more detailed predictions for the AGN and galaxy populations, and build customised AGN-focused mock survey catalogues for comparison with observations.

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## Session XIV: Centre of Galaxies III

## Session Chair: Lucia Armillotta

**Julia Bryant (invited survey)**
University of Sydney/ AAO

*The SAMI Galaxy Survey: Origins of Gas in Galaxies Traced by Kinematic Misalignments*

The degree of alignment between the stellar and gas kinematics of a galaxy can indicate the origin of gas accreted into galaxies. The SAMI Galaxy Survey is amassing optical integral field spectroscopy of ~3800 nearby galaxies across a broad range in stellar mass, morphology and environment (from field galaxies to groups to clusters). Based on ionised gas and stellar kinematics in the SAMI galaxies, we have investigated the impact of galaxy morphology and environment on the way galaxies are fed and process accreted gas.

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**Mark Krumholz (invited review)**
Australian National University

*Star Formation, Fuelling, and Feedback in Galactic Centres*

In this talk I discuss the problem of how star formation is fuelled and regulated in the central few hundred of parsec of spiral galaxies, and how these processes interact with the growth of black holes. I argue that transport of mass interior to galaxies' inner Lindblad resonances is driven primarily by acoustic rather than gravitational instabilities, and that this mechanism coupled to stellar feedback explains a number of otherwise-puzzling observations, including the Milky Way centre's lack of dense gas or star formation except in the ~100 pc ring, and the dispersion of star formation rates and efficiencies in the centres of nearby galaxies.

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**Pei-Ying Hsieh**
Institute of Astronomy and Astrophysics, Academia Sinica

*The Fossil Nuclear Outflow in the Central 30 pc of the Galactic Center*

In Hsieh+ (2015, 2016, ApJ), we report a new 1 pc (30") resolution CS(J=2-1) line map of the central 30 pc of the Galactic center (GC), made with the Nobeyama 45 m telescope. We revisit our previous study of an extraplanar feature called the polar arc (PA), which is a molecular cloud located above SgrA*, with a velocity gradient perpendicular to the galactic plane. We find that the PA can be traced back to the galactic disk. This provides clues to the launching point of the PA, roughly 6x10^6 years ago. Implications of the dynamical timescale of the PA might be related to the Galactic center lobe at parsec scale. Our results suggest that, in the central 30 pc of the GC, the feedback from past explosions could alter the orbital path of molecular gas down to the central tenth of a parsec. In the follow-up work of our new CS(J=2-1) map, we also find that, near systemic velocity, the molecular gas shows an extraplanar hourglass-shaped feature (HG-feature) with a size of ˜13 pc. The latitude-velocity diagrams show that the eastern edge of the HG-feature is associated with an expanding bubble B1, ˜7 pc away from SgrA*. The dynamical timescale of this bubble is ~3x10^5 years. This bubble is interacting with the 50 km/s cloud. Part of the molecular gas from the 50 km/s cloud was swept away by the bubble to b=-0.2 degree (27 pc from SgrA*). The western edge of the HG-feature

seems to be molecular gas entrained from the 20 km/s cloud toward the north of the galactic disk. Our results suggest a fossil explosion in the central 30 pc of the GC, a few 10^5 years ago.

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**Enrico Di Teodoro**
Australian National University

*Atomic Hydrogen Clouds Tracing the Galactic Nuclear Outflow*

We present the results of a new deep survey of neutral hydrogen above and below the Galactic Center with the Green Bank Telescope, extending up to Galactic latitude | b | < 10 degrees. The survey reveal the existence of a population of anomalous high-velocity clouds extending up to heights of 1.5 kpc from the Galactic Plane and showing no signature of Galactic rotation. These clouds have local standard of rest velocities | VLSR | < 350 km/s, typical sizes of few tens pc and neutral hydrogen masses of a few hundreds solar masses. We model the cloud kinematics in terms of an outflow expanding from the Galactic Center and find the population consistent with being material moving with radial velocities 300 km/s < Vw < 400 km/s inside a bi-cone with opening angle $\alpha > 140$ degrees. These clouds likely represent the cold gas component entrained in the nuclear wind driven by our Galaxy.

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**Joss Bland-Hawthorn**
Sydney Institute for Astronomy, University of Sydney

*The Milky Way – Evidence for Seyfert Activity in the Recent Past*

The Galaxy's supermassive black hole is a hundred times closer than any other massive singularity. It is surrounded by a highly unstable gas disk so why is the black hole so peaceful at the present time? This mystery has led to a flurry of models in order to explain why Sgr A* is radiating far below (1 part in 108) the Eddington accretion limit. But has this always been so? Evidence is gathering that Sgr A* has been far more active in the recent past, on timescales of thousands of years and longer. The bipolar wind discovered by MSX, the gamma-ray bubbles discovered by Fermi-LAT, the WMAP haze, the positronium flash confirmed by INTEGRAL, are suggestive of something truly spectacular in the recent past. We present new evidence that the Galactic Centre was a full blown "active galaxy" just two million years ago. The echo of this incredible event can be seen today imprinted across the Galaxy.

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## Session XV Centre of Galaxies IV

## Session Chair: Julia Bryant

**Sebastian Bustamante Jaramillo**
Heidelberg Institute for Theoretical Studies

*Spin Evolution of Supermassive Black Holes in a Cosmological Context*

Supermassive black holes (BH) at the center of galaxies grow their mass through two different channels, namely gas accretion and BH-BH coalescence. These processes lead not only to an increase of the mass, but also modify the spin of the BHs, which in turn, affects the accretion power that regulates star formation and gas cooling in the host galaxy. Thus, modelling spin is an important step to better understand the co-evolution of BHs and their hosts. Spin evolution in the context of galaxy formation has been previously investigated mostly through post-processing approaches, with only few studies using self-consistent on-the-fly models. The latter is a necessary consideration to properly capture the effects on the radiative efficiency and the accretion power. In this work, we implement in the N-body, magneto-hydrodynamics code AREPO, a semi-analytical model of spin evolution coupled to the numerical output for the mass accretion rate and the angular momentum of accreted gas. The model assumes a geometrically thin cool warped alpha-disc which accretes mass and angular momentum from the surrounding gas, and the spin magnitude and orientation are evolved on the fly. We optionally consider spin-dependent BH radiative efficiencies, which enables us to study the influence of spin on BH feedback, and thus on the properties of the host galaxy. We also examine two different modes of spin evolution, chaotic and coherent accretion. We have run a set of cosmological simulations with different configurations of these models, allowing us to quantify their impact on the BH population, the galaxy properties, and their scaling laws.

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**Natalia Eiré Sommer**
RSAA ANU

*Reverberation Mapping with DES/OzDES*

It has recently been shown that, by utilising the method of reverberation mapping, it may be possible to use active galactic nuclei (AGN) as standard candles. The presence of AGN at high redshifts implies the possibility of probing a larger volume of the Universe, and the nature of dark energy. The Dark Energy Survey (DES) and the Australian Dark Energy Survey (OzDES) are together targeting AGN for this purpose, and expect to increase the number of AGN with reverberation mapping estimates by a very significant amount on world basis. In this talk I will present the current state of the DES/OzDES reverberation mapping project, the challenges we are facing, and the very promising results we are expecting to obtain.

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