KIAA Forum on Gas in Galaxies: Star Formation and Quenching

Kavli Institute for Astronomy and Astrophysics, Beijing, 18-22 June 2018

Contributed talks

Session I. Environments

Tao Wang (University of Tokyo)

How do massive cluster galaxies die? Insights from a census of molecular gas in the most distant clusters at z=2.5

It has long been recognized that local environment plays a crucial role in shaping the formation and evolution of galaxies. While clear evidence of an enhanced fraction of quiescent galaxies in dense environments has been shown for low-mass galaxies, however, it remains unclear whether and how the environment influence the most massive galaxies (Mstar > 10^11 Msun). Based on observations with ALMA, IRAM-NOEMA and VLA, here we present a census of molecular gas and dust properties of a complete sample of massive galaxies in the most distant known X-ray cluster at z=2.51, which reveals a clear cluster-centric radius dependence of star formation rates and gas content for cluster members, with those closer to the cluster core being increasingly gas-poor and less actively forming stars. An elevated star formation efficiency (SFE, relative to galaxies in the field) is also observed for most cluster galaxies, suggesting that most of them will be quenched in around ~300 Myrs. This provides one of the first direct pieces of evidence for the influence of environment on the gas reservoirs and SFE of z>2 cluster galaxies, thereby providing new insights into the rapid formation and quenching of the most massive galaxies in the early universe.

Tobias Westmeier (ICRAR / UWA)

On the flatness of the HI mass function in group environments

I will present the results of deep HI observations of the Sculptor group filament with the 64-m Parkes telescope and the Australia Telescope Compact Array. While we detect several new, faint HI sources in our data set, the overall HI mass function (HIMF) of the Sculptor filament is significantly flatter than the global HIMF from HIPASS or ALFALFA and more consistent with the flat HIMFs recently discovered in other group environments. The flatness of the HIMF suggests that some physical process must have removed gas from low-mass galaxies in group environments. I will discuss several of these potential processes in more detail and demonstrate how the upcoming HI surveys with SKA precursor and pathfinder instruments can help us in identifying the origin of environmental variations in the HI gas content of galaxies.

Joanna Woo (University of Victoria)

Galaxy Quenching, Structural Transformation and the Environment

It is well established that environment plays a role in the quenching of star formation in galaxies. In addition, it is becoming increasingly clear that the stars in quenched galaxies in dense environments have prominent bulges, or equivalently, are centrally concentrated/compact, having high central stellar mass surface densities. I will present new work that explores the relationship between these two effects, namely environment quenching and the build-up of galaxy inner densities. In particular, I will present strong evidence for a separate quenching path for satellites relative to the field. This study has raised new questions as to how or if environmental processes cause structural change. I will present new MUSE IFU observations of a group of galaxies showing evidence for a rise in central density caused by the group environment in some cases, and in others, evidence that the central densities were established long before quenching.

Bumhyun Lee (Yonsei University)

The impact of ram pressure on the molecular gas probed by SMA and ALMA

Ram pressure stripping is an important environmental process, which causes star formation quenching by effectively removing cool interstellar gas from galaxies in high density environments. Although the observational evidence of diffuse atomic gas stripping has been reported by many HI imaging studies, it is still unclear whether molecular gas, a more direct ingredient for star formation, can also get stripped by ram pressure or not. In this talk, I will present the results of CO data from SMA and ALMA of three Virgo spirals (NGC 4330, NGC 4402, NGC 4522) that are experiencing active HI gas stripping. We find that even molecular gas located inside the stellar disk can be also disturbed by strong ram pressure, as in HI gas. Particularly, for NGC 4522, the ALMA detection of extraplanar 13CO emission highly suggests that the molecular gas can be directly stripped by ram pressure. Comparing with UV and Hα, I will discuss how star formation activity of cluster galaxies is changed as the cold dense interstellar gas is influenced by ram pressure.

Marco Grossi (Observatório do Valongo, UFRJ)

Environmental effects on the gas components of Virgo star- forming dwarf galaxies

Star-forming dwarf (SFD) galaxies are unique laboratories to investigate the properties of the interstellar medium and the efficiency of the star formation process in the low-metallicity regime. Moreover, due to the fragility of their stellar and gaseous discs, they are sensitive probes of the environment where they are evolving, providing clues on the process of morphological transformation induced by the interaction with their surroundings. We present integral field spectroscopy (IFS) observations of a sample of SFDs in the Virgo cluster obtained with PMAS/PPAK at the Calar Alto 3.5 meter telescope. The targets have different levels of atomic hydrogen gas deficiency (i.e. from none to high) implying different stages of interaction with the surrounding environment. We analyse the ionized gas morphology and compare the gas and stellar kinematics, to study the impact of a high-density environment on the ionized gas component and on the decrease of their star formation activity. We combine IFS data with atomic hydrogen maps, optical images from the Next Generation Virgo Cluster survey, Herschel and IRAM 30m-telescope observations providing information on their dust and molecular gas content. We discuss the mechanisms that are progressively quenching the star formation activity of these systems, and how the different components of the interstellar medium are affected by the cluster environment.

Lizhi Xie (Observatory of Trieste)

On the influence of environment on the sizes of gaseous and stellar disks

I will present a work of the influence of the environment on the gas content and gaseous/stellar disk sizes of star forming galaxies that use a state-of-art semi analytic model for GAlaxy Evolution and As- sembly (GAEA), and observational information from the Ha3 and HAGGIS surveys. We analyse the origin of differences between central and satellite galaxies using different model samples, constructed mimicking the observational selection. We find that, in our model, (i) differences in molecular gas content and star formation activity always arise from environmental effects; (ii) size differences are already found before galaxies become satellites and are driven by a different halo assembly history of the hosting dark matter haloes; (iii) differences in HI masses can be found at accretion or can arise from environmental effects, depending on the selection adopted. Our model predicts that molecular gas is affected more strongly/effciently than HI, in contrast with observational measurements. In addition, model satellites have lower star formation rates than observed ones. We argue that these inconsistencies could be largely resolved with the inclusion of a proper treatment for ram-pressure stripping of cold gas. A more sophisticated treatment of angular momentum exchanges, accounting for the multi-phase nature of the gaseous disk is also required.

Session II. SFMS

Barbara Catinella (ICRAR/University of Western Australia)

Cold gas and star formation in galaxies: insights from the xGASS survey

A detailed knowledge of how gas cycles in and around galaxies, and how it depends on their structural and star formation properties, as well as environment, is crucial to understand galaxy formation and evolution. This requires sensitive surveys of cold gas for representative samples of galaxies, able to probe the gas-poor regime.

I will present results based on the recently completed, extended GALEX Arecibo SDSS Survey (xGASS), a gas fraction-limited census of the HI content of ~1200 galaxies, selected only by stellar mass and redshift. These are the deepest observations of cold gas in nearby (z<0.05) galaxies currently available. I will discuss how xGASS is shedding light on the processes that regulate the position of galaxies on the stellar mass-star formation plane.

Ryan Chown (McMaster University)

Transition galaxies and the relationship between cold gas and quenching

Recent surveys of the cold gas component of nearby galaxies have enabled a better understanding of star formation for the nearby galaxy population. By combining measurements of molecular and atomic gas with other observed galaxy properties the physical mechanism(s) responsible for quenching can be constrained. Galaxies transitioning from the star forming main sequence to the passively evolving population have intermediate specific star formation rates but exhibit a wide range in other properties (e.g. gas content, NUV-r and g-r colours, AGN content, gas phase metallicity). Using molecular gas measurements from the JINGLE and xCOLD GASS surveys, and atomic gas measurements from the ALFALFA and xGASS surveys, I will show recent results of cold gas scaling relations for transition galaxy populations, including green valley galaxies and red star-forming galaxies. I will discuss what cold gas and other properties can tell us about quenching from the main sequence.

Fu Jian (Shanghai observatory)

HI gas component in dwarf galaxies in the view of semi-analytic models

In this talk, we will show our recent progress on semi-analytic models of galaxy formation, which mainly focus the HI gas component in low mass galaxies. Our models based on the SAMs codes L-Galaxies and run on the Aquarius haloes and ELUCID halos to study the local dwarf galaxies, and we use the presciprtions related to interstellar surface densities, metallicities and UV back ground field to calculated the HI gas components in ISM. Based on our models, our main results are

(1) Our models can fit the HI mass function from ALFALFA to very low mass end, and the low mass end of HIMF is very sensitive to the physical processes in low mass satellites, e.g SN feedback, ram pressure stripping.

(2) Our models predict a lot of gas rich low mass dark galaxies, which may offer opportunities for future HI 21cm survey in neary by galaxies by FAST and SKA-1.

(3) The tight correlation between HI disk size and HI mass can be extended to very low mass range ($M_{HI} \sim 10^7 M_{sun}$), which means the prescription between atomic and molecular gas should be valid in low mass galaxies with low gas metallicity

(4) The minor mergers processes between HI rich satellites and central galaxies contribute a large fraction of HI source in gas accretion.

Tjitske Starkenburg (Center for Computational Astrophysics, Flatiron Institute)

The populations of star forming and quenched galaxies

Galaxies having little to no active star formation are termed "quenched" but the definition of "quenched" varies widely through the literature. Moreover, the galaxy star formation sequence itself, whether predicted from simulations or observed, varies depending on the dataset and the star formation and quenching indicators used.

We explore star formation and quenching of galaxies in a large observational dataset plus numerous independent sets of simulated galaxies from large-scale and zoom cosmological simulations. We describe the populations in the star formation rate - stellar mass plane and discuss the differences between the datasets. Moreover, we build mock galaxy spectra for all simulated galaxies and compare the observational star formation and quenching indicators for the mock galaxy spectra to the galaxy properties in the simulations and to the star formation and quenching indicators for observed galaxies.

We describe the star forming and quenched population of isolated galaxies in theoretical predictions, mock observations, and observational data, how to define quenching in a consistent way, and the implications of this comparison on the star formation and feedback processes in galaxies.

Miguel Socolovsky (University of Nottingham)

Victims of their own success: rapidly-quenched cluster galaxies at $0.5 < z < 1.0$

Post-starbursts (PSBs) are a rare population of galaxies in which star-formation was rapidly quenched sometime within the last few hundred Myr. As a consequence, these systems provide a valuable 'snapshot' of galaxy evolution shortly after an event that quenched their star formation. In this talk, I will present some recent results on the impact of the galaxy environment on this population, and their star-forming progenitors, at $0.5 < z < 1$. Using data from UKIDSS Ultra Deep Survey (UDS), I will show that stellar mass functions reveal a strong excess of low-mass PSB galaxies in the cluster environment, compared to the field. I will also show that the likely progenitors of this galaxy population are low-mass field galaxies with high specific star formation rates (sSFR). These results suggest environmental quenching is a significant driver in the evolution of these low-mass systems. The structure (effective radius and Sersic index) of these galaxy populations also provides some further insight into the nature of this environmental quenching. For high-sSFR galaxies, we find that those in the cluster environment have on average larger sizes than those in the field. This trend seems to be driven by the absence of the most compact high-sSFR galaxies in the cluster environment. Moreover, we find that cluster PSBs are similar in structure to this missing high-sSFR population, suggestive of size-dependent environmental quenching among the low-mass star-forming population. I will discuss how these results suggest low-mass PSB galaxies were 'victims of their own success' and rapidly quenched by a combination of strong stellar feedback and environmental processes.

Session III. ISM & SF laws

Jing Wang (KIAA)

The Local Volume HI Survey: HI-star formation connections

We built a multi-wavelength dataset for galaxies from the Local Volume Hi Survey (LVHIS), which comprises 82 galaxies. We also select a sub-sample of ten large galaxies for investigating properties in the galactic outskirts. The LVHIS sample covers nearly four orders of magnitude in stellar mass and two orders of magnitude in Hi mass fraction (fHI). The radial distribution of Hi gas with respect to the stellar disc is correlated with fHI but with a large scatter. We confirm the previously found correlations between the total Hi mass and star formation rate (SFR), and between Hi surface densities and SFR surface densities beyond R25. However, the former correlation becomes much weaker when the average surface densities rather than total mass or rate are considered, and the latter correlation also becomes much weaker when the effect of stellar mass is removed or controlled. Hence the link between SFR and HI is intrinsically weak in these regions, consistent with what was found on kpc scales in the galactic inner regions. We find a strong correlation between the SFR surface density and the stellar mass surface density, which is consistent with the star formation models where the gas is in quasi-equilibrium with the mid-plane pressure. We find no evidence for Hi warps to be linked with decreasing star forming efficiencies.

Jiayi Sun (Department of Astronomy, Ohio State University)

Cloud-scale Molecular Gas Properties in Nearby Galaxies

I will show key results from PHANGS-ALMA, a large ALMA survey of the molecular ISM in about 80 nearby galaxies. PHANGS resolves the molecular medium at 1'' ~ 50-100 pc resolution (i.e., matching the size of an individual molecular cloud), and the field of view covers the whole area of active star formation in our targets. In Sun et al. (submitted), we use the first data from PHANGS to make fundamental structural measurements of the molecular gas in 15 galaxies. For an unprecedented sample of about 30,000 independent sightlines, each equivalent to a molecular cloud, we measure the distributions of molecular gas surface density and velocity dispersion. We show a strong correlation between the two. In high surface density regions, the slope of this relation is broadly consistent with the molecular ISM being in approximate energy equipartition between kinetic and gravitational potential energies. Our results imply that the molecular ISM shows a narrow range of virial parameter, but an enormous range of internal turbulent pressure. Our data also show that at low surface densities, in atomic-gas dominated regions, environment appears to exert a large influence on the dynamical state of molecular clouds. Following this work, we estimate the gas disk dynamical equilibrium pressure from archival stellar mass and HI maps, and find it to be comparable to the measured gas turbulent pressure. Combining these cloud-scale measurements with existing UV/IR data, we estimate the typical star formation efficiency per free fall time to be about 0.5% across the PHANGS-ALMA sample. This is the most direct estimate of this key quantity across a large sample of clouds and galaxies to date.

O. Ivy Wong (International Centre for Radio Astronomy Research/University of Western Australia)

Explaining the HI and star formation properties with a constant stability disk model

We examine the HI-based star formation efficiency (SFE; the ratio of star formation rate to the HI mass) and the HI size-mass relationship in the context of a constant stability star-forming disk model. Using a 2-fluid Toomre Q-parameter to describe the stability of a galactic disk, we find that the observed uniformity in SFE as well as the HI size-mass relationship can be well-described by a marginally stable disk model. The HI size-mass relationship implies that the HI gas density averaged over the entire HI disk is constant from galaxy to galaxy. Our marginally-stable disk model yields a similarly narrow range of HI gas densities in combination with a shallow power-law radial profile, as well as perfectly reproducing the observed HI size-mass relationship at low HI masses. While the rotational amplitude Vmax is the primary driver of disk structure in our model, we find the specific angular momentum of the galaxy may play a role in explaining a weak correlation between SFE and effective surface brightness of the disk. (Ref: Wong, O.I. et al 2016, MNRAS; Meurer et al 2018; Wong et al 2018, in prep)

Qian Jiao (Purple Mountain Observatory)

Neutral carbon emission in nearby galaxies as a molecular mass tracer

CO is widely used as molecular gas tracer in galaxies. However, several shortcomings have limited the ability of CO in tracing molecular gas, such as the dependence of CO-to-H2 conversion factor (X_CO) on metallicity and gas density, or its difficulty to observe in high-z systems. Therefore, finding some alternative molecular gas tracer is important and urgent. Here, we aimed to investigate whether neutral carbon emission can trace molecular gas in different types of nearby galaxies. We first present a statistical study on the [CI](1−0) (492.161 GHz) and [CI](2−1) (809.344 GHz) lines for a large sample-1 of nearby luminous infrared galaxies (LIRGs) observed with the Herschel SPIRE/FTS. For our sample-1, we investigate the correlation between L'CI(1−0) and L'CO(1−0), as well as L'CI(2−1) and L'CO(1−0). We find that L'CO(1−0) correlates almost linearly with L'CI(1−0) and L'CI(2−1), indicating that these two [CI] lines can be used as total molecular tracers in LIRGs, which is particularly useful for high-redshift galaxies. We further present the maps of [CI](1−0) and [CI](2−1) emissions in another sample-2 of local normal spirals, starbursts and Seyfert galaxies, at a sub-kpc scale using Herschel SPIRE/FTS. We find that the [CI](1−0) and [CI](2−1) distribute similarly with the CO (1−0) emission in most of our sample-2. We investigate the correlations between the luminosity of CO (1−0) and the luminosities of [CI] lines in sample-2, and find that the correlations of CO (1−0) and [CI] lines in (U)LIRGs continue to a sub-kpc scale in normal spirals, starbursts and Seyfert galaxies. The L’CO(1−0) correlates tightly and almost linearly with both L’[CI](1−0) and L’[CI](2−1) in these two samples, suggesting that the ability of [CI] lines in tracing bulk molecular gas in (U)LIRGs can extend to a much smaller scale in spirals, starbursts and Seyfert galaxies.

Jorge Moreno (Pomona College)

Galaxy Mergers on FIRE-2: Interstellar Gas Ecology

We employ a suite of 27 high-resolution galaxy merger simulations to investigate the connection between interaction-induced star formation and the behaviour of various gas phases in the interstellar medium (ISM). This work uses the GIZMO code, along with the second version of the “Feedback in Realistic Environments” model (FIRE-2). This framework captures the multi-phase structure of the ISM. We report an average enhancement in star formation rate of 27% across our sample, accompanied by an averaged 20 percent excess in molecular gas content. In other words, galaxy-galaxy interactions trigger intense star formation episodes whilst replenishing a reservoir of cold molecular gas. In general, the slow depletion of molecular gas is governed by consumption via star formation and conversion into ionized gas, due to feedback from new stars. Interactions interrupt this balance, resulting in short episodes in which gas compressions aids both star formation and the build up of the molecular gas reservoir. Most of the molecular gas content is too diffuse to form stars, resulting in a long-lived reservoir, which outlives the interaction-induced starburst. For the first time we have an statistically large example of merger galaxies capable of simultaneously exploring orbital parameter space and resolves Giant Molecular Clouds with feed-back regulated star formation in a realistic fashion.

Yuan Wang (Max-Planck-Institute for Astronomy)

Dense gas in Giant Molecular Filaments: Connecting the Milky Way to other galaxies

While extragalactic molecular gas surveys imply a connection between star formation properties, global cloud and environmental parameters, empirical evidence shows that star formation in the Milky Way is related to the high density material in the molecular clouds (MCs), and suggests a 'universal' column or volume density threshold for star formation in local clouds and typical spiral galaxies. We present a pilot study of the dynamics of the dense gas of an entire Giant Molecular Filaments (GMF54), which is an analog to the objects dominating typical extragalactic observations. We mapped the dense gas of GMF54 (~45pc) with the IRAM 30m telescope, covering the 1-0 transition of the common dense gas tracers HCN, HNC, HCO+ and their 13C isotopologue molecules, as well as the cold dense gas tracer N2H+. We will present the dense gas fraction, the line ratios and the probability density function (PDFs) for the molecular column densities of the filament. Furthermore, we connect the line ratios with the PDFs, and compare with the extragalactic observations. Our results provide the crucial ``sub-beam'' density distribution of material within clouds for the extragalactic studies.

Special session: New facilities

Christian Wolf (Australian National University)

Dust and extinction trends in star-forming galaxies

We measure dust extinction in normally star-forming galaxies, separately for the diffuse dust and clumpy dust surrounding star-forming regions. The diffuse dust can be constrained via the inclination dependence in appearance of a galaxy, while the clumpy dust can be inferred by comparing the strength of the H-alpha line compared to the Paschen-alpha line. This work has been enabled by combining deep near-UV continuum data from COMBO-17, deep Spitzer 24 micron data, deep H-alpha line imaging with the 10.4m-GTC, deep Paschen-alpha line imaging with PANIC and inclination measurements from deep HST/ACS imaging, for all the same galaxies. Crucially, all quantities are obtained for the entire galaxies and not through aperture-restricting fibres. This data set allows us to disentangle clumpy dust from diffuse dust. When measuring the clumpy dust component in star-forming regions, we find no dependence of the dust column on the galaxy mass, but a strong dependence on star-formation rate, consistent with a Schmidt law and a constant gas-to-dust ratio.

MING ZHU (NAOC)

Fast status and Gas in Galaxy Groups

Using the group crossing time t_c as an age indicator for galaxy groups, we have investigated the correlation between t_c and the group spiral fraction, as well as between t_c and the neutral hydrogen (HI) gas fraction of galaxy groups. Our galaxy group samples are selected from the SDSS Dr7 catalog, and the Galaxy Zoo morphological data are used to derived the fraction of spiral galaxies in groups. We found that the group spiral galaxy fraction is correlated with the group crossing time. We further cross matched the latest released ALFALFA 70% HI source catalog with SDSS group catalog and have identified 163 groups from the SDSS survey whose total HI mass can be derived by summing up the HI mass of all the HI sources within the group radius. Our sample groups cover a wide range of halo masses and they are distributed in different cosmic environments. We also derived and calculated the virial mass and the HI mass fraction. We found a correlation between the HI mass fraction and the group crossing time. We suggest that this correlation can be explained by HI gas depletion due to environmental effects or star formation during the evolution of galaxy groups. We propose to extend such study with a much larger sample of galaxy groups based on the future extragalactic HI survey using the Five hundred-meter Aperture Spherical radio Telescope (FAST) in China.

Bi-Qing For (ICRAR/University of Western Australia)

ASKAP HI Surveys

The ASKAP extragalactic HI surveys, WALLABY, DINGO and FLASH, will allow us to map out the distribution and amount of HI in galaxies across cosmic time (< 8 Gyr). Early science programs have been commenced in late 2016. In this talk, I will introduce these HI surveys (WALLABY, DINGO and FLASH), give an update on early science programs and progress toward full operation of ASKAP.

Marc Verheijen (Kapteyn Astronomical Institute)

HI imaging surveys with Apertif

Apertif is an innovative phased-array receiver system currently being commissioned on the Westerbork Synthesis Radio Telescope as a technology pathfinder for the Square Kilometer Array. With its 8 sq-deg field-of-view and 300 MHz bandwidth, it increases the survey speed of the WSRT for 21cm line emission by a factor 20. Operating at 1130-1430 MHz, it will image the distribution and kinematics of the HI gas in hundred thousand galaxies out to z=0.25 and produce nearly confusion-limited radio continuum images in full polarisation. In this talk I will present the expected performance of Apertif, outline the plans for a Shallow Northern-sky Survey and a Medium-Deep survey, and discuss the main science projects currently envisioned, with a focus on the environmental effects on galaxy evolution and the life cycle of gas in galaxies.

Jeff Wagg (SKAO)

Prospects for studies of atomic and molecular gas with the SKA

The first phase of the Square Kilometre Array represents the next major step in the evolution of radio astronomy. The baseline design consists of two telescopes - a low frequency aperture array in Western Australia and a mid to high frequency array dishes in the Karoo of South Africa. These telescopes will study the evolution of gas in galaxies and the intergalactic medium from the end of the Dark Ages to the present day. I will summarise the current design activities and describe some of the ways that SKA1 could be used to study atomic and molecular gas in the interstellar medium of galaxies.

Session IV. Accretion

Paolo Serra (INAF - Osservatorio Astronomico di Cagliari)

EAGLE and the gas accretion history of early-type galaxies

I will present the results of a comparison between the observed and EAGLE simulated HI properties of early-type galaxies. I will show that EAGLE delivers an excellent match to the broad distribution of HI mass, morphology and kinematical misalignment of early-type galaxies with M(star)>1e+10 Msun in all environments. It can therefore be rewinded to understand how early-type galaxies got this properties. I will discuss whether gas-rich minor mergers are the main source of low-z gas accretion onto early-type galaxies.

Toby Brown (McMaster University)

Evidence for gas accretion regulating the scatter of the mass–metallicity relation

Gas accretion and star formation are two of the most essential processes in the evolution of galaxies. Often probed using the observational relationship between stellar mass, gas-phase metallicity and current star formation rate, recent work shows observable links with atomic gas (HI) content also exist. Despite this, the intrinsic faintness of HI means that establishing whether gas or star formation is the most important factor in this picture has so far not been possible. In this talk, I show how we overcome this obstacle by stacking HI spectra for 10,000 nearby galaxies - the largest sample for which atomic gas and metallicity information is available - along the mass-metallicity relation. We confirm and quantify the strong anti-correlation between HI mass and gas-phase metallicity at fixed stellar mass. Furthermore, we show for the first time that the relationship between gas content and metallicity is consistent between different metallicity estimators, contrary to the weaker trends found with star formation which are known to depend on the observational techniques used to derive oxygen abundances and star formation rates. When interpreted in the context of theoretical work, this result supports a scenario where galaxies exist in an evolving equilibrium between gas, metallicity and star formation. The fact that deviations from this equilibrium are most strongly correlated with gas mass suggests that the scatter in the mass-metallicity relation is primarily driven by fluctuations in gas accretion.

Michael Rauch (Carnegie Observatories)

Observational constraints on the gaseous environment of galaxies at high redshift

Observationally, little is known about how galaxies are fed by gas at high redshift. Scientific interpretation of QSO absorption line data, our main source of information on the IGM, has focused on the "circumgalactic medium" paradigm, a scenario, where galaxies are supposed to influence their gaseous environment through galactic outflows. While the ubiquity of these outflows has been established, their range and importance for the properties of the IGM has not been ascertained. Observational evidence is consistent with the idea, that most galaxies are fed by low metallicity, in-falling gas that has been polluted with metals at a time pre-dating the existence of the galaxies it is accreting on. I will show some new observational evidence on the properties of the accreting gas, and discuss new techniques of observing the gaseous environment of galaxies at high redshift.

Marijana Smailagic (University of California, Santa Cruz)

The cold circumgalactic medium of luminous red galaxies

Luminous red galaxies (LRGs) are the most massive galaxies at z~0.5 and are selected to have negligible star formation. Previous studies showed that the amount of cold HI gas in the circum-galactic medium (CGM) of intermediate-mass galaxies increases with mass. On the other hand, theory predicts that massive galaxies have little cold gas. However, observations showed that ~5% of sightlines probing LRG-CGM show significant MgII absorption, which traces cold gas. We obtained HST/COS spectra to study the CGM of 15 LRGs, 7 of which already have detected MgII in SDSS spectra. In the CGM of two LRGs, we found strong metal lines, with HI and CIII equivalent widths and velocity spreads that exceed all local ~L* galaxies (HI and CIII have widths of up to ~5.6A and ~2A, and extend up to

~1300 and ~2000 km/s). This shows that some massive quenched galaxies contain significant amounts of cold gas in their CGM. For the whole sample, we found that HI is often strong, and is detected in the CGM of 3 of 8 of LRGs without MgII. The LRG-CGM is detected out to ~380 kpc, and does not show clear correlation with impact parameter. We found that the LRG-CGM could originate from past activity (such as outflows from the intense star-formation, or an active galactic nucleus), that happened ~1 or few Gyr ago. The cold gas could either survive in hot massive halos for long time, or it could be formed later due to thermal instabilities. This indicates that the quenched galaxies are still surrounded with significant amounts of cold gas in their CGM, and that some mechanisms prevent this gas from accreting into central galaxies and forming stars. At the end, we discuss evolutionary connection between LRG-CGM and CGM of massive galaxies at lower and higher redshifts, including quasar host galaxies, submillimeter galaxies, and massive early-type local galaxies.

Nicole Melso (Columbia University)

Simulating Gas Inflow at the Disk-Halo Interface

The disk-halo interface is a crucial boundary between the galactic halo and the galactic disk where inflowing gas and outflowing gas interact. High-resolution simulations are needed to predict detailed gas properties at this interface and understand the final stages of accretion. Using a series of small-box hydrodynamic ENZO simulations, we have studied the interaction between bursts of filamentary inflow and supernovae-driven outflow at the disk-halo interface, achieving pc-scale resolution with Adaptive Mesh Refinement. We have used these simulations to quantify the properties of the inflowing gas in contact with the inhomogeneous outflow. This inflowing material is the fuel for future star formation and will directly influence the evolution of the galaxy. I will discuss the cooling, fragmentation, mixing, and accretion of this inflowing gas at the disk-halo interface. In addition, we have used these simulations in tandem with CLOUDY photoionization modeling to predict observational signatures of gas accretion, including H-alpha emission features and HI column densities. I will discuss these results in the context of existing observations as well as prospects for upcoming observations with high-sensitivity spectroscopic instrumentation.

Session V. Outflows

Tom Oosterloo (Netherlands Institute for Radio Astronomy)

Outflows of cold gas in young radio galaxies

Our view of the gas and its physical conditions in the central region of AGN has been enriched by the discovery of fast, massive outflows of molecular gas in AGN. These outflows can be driven by radiation from the AGN, but also by the interaction of the ISM with the

plasma jets ejected by the AGN. These outflows impact on the growth on the central supermassive black hole as well as on the star formation (by quenching it or, on fact, stimulating it) of the host galaxy.

Much of the detailed physics of these gas outflows, and their actual impact on the host galaxy, is still not well understood. Understanding the origin of these outflows and quantifying their impact requires tracing their location and deriving their physical conditions (density, mass, mass outflow rate and kinetic energy etc.).

We will present the results from recent ALMA observations which have allowed to study the details of the molecular outflows in two radio galaxies where the young radio jets play a key role in shaping the surrounding gaseous medium. The data on multiple transitions allow us to derive the physical conditions in the different regions of the outflowing molecular gas. We will describe the kinematics of the gas and its conditions, with particular emphasis on the comparison with other phases of the ISM (HI and ionised gas).

Based on a comparison with detailed numerical simulations, for one of the objects we obtain a detailed three-dimensional picture of the outflow and its kinematics and find that outflowing molecular gas is present across the entire region co-spatial with the radio plasma, providing unambiguous evidence that the radio jets/cocoon are responsible for the outflow. The signature of the impact of the radio jet is clearly seen in the spatial distribution of the excitation temperature and pressure of the outflowing gas, with the highest excitation and pressures found for the gas with the highest outflow velocities. The detailed information about the physical condition of the gas in this fast outflow will serve as template for the signatures of the impact of a radio plasma jet on a gas-rich ISM and guide the studies of outflows in other galaxies, including higher redshift objects.

Heidi White (Swinburne University)

Testing Feedback Regulated Star Formation in Turbulent, Thick Disks

I will present results using the DYNAMO sample of nearby galaxies. These extremely rare galaxies are very well matched in gas fraction (fgas~20-80%), kinematics (rotating disks with velocity dispersions ranging 20-100 km/s), structure (exponential disks) and morphology (clumpy star formation) to high-z main-sequence galaxies, however DYNAMO are located at z=0.1. We therefore use DYNAMO galaxies as laboratories to study the processes inside galaxies in the dominate mode of star formation in the Universe, and carry out targeted, complementary studies to large surveys at high redshift. We have, for example, used DYNAMO galaxies to study the impact of resolution effects in clumpy galaxies, and the violent disk instability model of clumpy galaxy evolution. In this talk I will report on results from our programs with HST, Keck and NOEMA for DYNAMO galaxies that are aimed at testing feedback regulated models of star formation. We have discovered of an inverse relationship between gas velocity dispersion and molecular gas depletion time. This correlation is directly predicted by theories of feedback regulated star formation. I will also use the relationship between pressure and SFR surface density to further test models of feedback regulated star formation. I will show that while the observed relationship between pressure and SFR surface density is qualitatively similar to predictions from models of feedback regulated star formation, there are however large quantitative differences between matching data and current theoretical models. I will discuss the implication of these differences on the amount of momentum injected into the ISM from star formation feedback. If time permits, I will also present preliminary results measuring outflows of clumps from Keck observations of MgII.

Bernd Husemann (Max Planck Institute for Astronomy)
The gas reservoir in AGN host galaxies and the multi-phase impact of outflows

The impact of AGN on their host galaxies remains a highly controversial topic with the baseline assumption that AGN suppress star formation as guided by cosmological simulations. In this framework, I will present the results on the gas content and star formation properties for a large sample of luminous AGN at low redshift by combining sub-mm data with optical integral-field spectroscopy. The observations show that most AGN host galaxies appear to have the same properties as normal massive star-forming galaxies surprisingly indicating no global impact of the AGN in most cases. This is likely related to mounting evidence that AGN outflows are only efficient within the central kpc of their galaxies. As part of the Close AGN Reference Survey (CARS) we are resolving the multi-phase nature of these compact outflows by combining observations with VLT-MUSE (ionized gas), Gemini-NIFS (warm-molecular gas), ALMA (cold molecular gas) and JVLA (HI and radio jets). Those observations reveal that the compact outflows can indeed clear the gas and thereby suppress the star formation in the central region. While the impact is not significant for the entire disc growth it will likely contribute to the self-regulation of the bulge growth.

Alice Concas (Excellence Cluster Universe)

Two-Face(s): ionized and neutral galactic winds in the local Universe.

The physical mechanism(s) driving the "quenching" of the star formation activity in galaxies, remains one of the least understood puzzles in the galaxy formation theoretical framework. According to the most recent theoretical models, the energetic feedback from active galactic nuclei (AGN) is believed to provide an effective mechanism to eject the gas away from the galaxy by powerful winds in very massive galaxies. However, below halo masses of 10^12Mo the galactic winds driven by the energy and momentum imprinted by massive stars to the surrounding ISM, are believed to be sufficiently energetic to eject the gas away from the galaxy potential well and stop the star formation.

In order to unmasking the nature of these two quenching processes (AGN and SF), we analyzed a complete spectroscopic galaxy sample (~600 000 spectra) drawn from the SDSS to look for evidence of galactic winds in the local Universe.

We focused on the shape of the [OIII]λ5007 emission line and interstellar Na I λ5890, 5895 (Na D) resonant line profiles as tracers of ionizing and neutral gas outflows, respectively.

I will show how the average [OIII]λ5007 and NaD line profile changes as function of star formation rate (SFR), stellar mass, disk inclination and nature of the dominant ionizing source in different BPT classes.

We find that, statistically, only “Light Breeze" can be observed in the local Universe only in AGN dominated sources. For purely SF galaxies we do not observe ionized gas outflows regardless of the SFR level. Only at very high SFR we detect a blue-shifted NaD line profile, likely indicating bulk motion of neutral gas from the disk. The additional analysis of Manga IFU data for a galaxy subsample (~1000 galaxies) sheds light on the different nature of the [OIII]λ5007 and NaD line profile outflows.

Both the integrated and spatially resolved data show that the galactic winds in local Universe have “Two Faces” which are related to two different ejection mechanisms, namely the neutral outflowing gas phase connected to the star formation rate along the galaxy disk and, the ionized winds related to the AGN feedback.

Miao Li (Center for Computational Astrophysics, Flatiron Institute)

How Supernovae-driven Hot Outflows Regulate Circumgalactic Medium

The circumgalactic medium (CGM), where cosmic inflows interact with feedback-driven outflows, provides critical clues for galaxy formation. The physics of feedback remains a bottleneck to theoretical modeling. In this talk I will introduce our numerical simulations of CGM impacted by supernovae (SNe)-driven hot outflows. Using outflow models that are directly obtained from our small-box high-resolution simulations, we study the large-scale evolution of the outflows in the CGM. The volume-filling hot outflows carry the majority of the energy and metals produced by SNe, and can travel to > 100 kpc from Milky Way-like galaxies. I will talk about how galaxy potentials, existing halo gas, and SF activity affects the impact of outflows. I will also discuss how the model can be compared against future X-ray observations and signals of the Sunyaev-Zel’dovich effect.

Session VI. Evolution(z)

Ran Wang **(Kavli Institute for Astronomy and Astrophysics, Peking University)**

Imaging the gas componet in the most distant quasar

Bright dust continuum, [C II], and CO line emission are detected in the host galaxies of the quasar host galaxies at z>~6, which probes the interstellar medium and star forming activity at an early epoch of supermassive black hole and galaxy formation. We are pursuing millimeter and radio observations to study the dust and gas components in these earliest quasar host galaxies. In this talk, I would like to present our recent observations of [C II] 158 micron line emission from the z~6 quasar hosts using ALMA. The deep ALMA imaging allow us to map the distribution of star-forming gas at the nuclear region, resolved velocity field, constrain the dynamical masses of the quasar hosts and search for possible evidence of AGN feedback.

Lingyu Wang (SRON Netherlands Institute for Space Research and University of Groningen)

Multi-wavelength synergy unleashes the full power of Herschel - The galaxy main sequence from z~0 to 6

To probe the dust obscured star formation in the early epochs, we need far-infrared and sub-millimetre observations. The deep Herschel-SPIRE maps contain most of the emission in the cosmic infrared background. However, SPIRE suffers from confusion due to its relatively large beam. We have since invested major effort in developing techniques which can use very deep optical/NIR prior catalogs to decompose Herschel data, as the full power of Herschel can only be unleashed when combined with detailed knowledge of the physical properties of galaxies. A breakthrough is our development of XID+ (Hurley et al. 2017) - a Bayesian framework in which to include prior information, and uses the Bayesian inference tool Stan (Stan Development Team, 2015a, b) to obtain the full posterior probability on flux estimates. Compared to the previous state-of-the-art, we can probe much fainter sources at the same flux accuracy of 10%. Another significant improvement is that with XID+, we can fully explore the correlations between sources which were not possible before. Using ALMA 870 micron data as an independent validation, we have shown, by including informative weak prior on the SED, the performance of XID+ can be improved further to an impressive depth of ~10 times below the confusion limit (Pearson, Wang, van der Tak et al. 2017). We exploit our super de-blended Herschel photometry, thanks to the power of multi-wavelength synergy, to study the star formation stellar mass relation (SSR, commonly known as the galaxy main sequence). We are able to measure the shape, width and cosmic evolution of the SSR in a self-consistent manner including dust obscured SF from z~0 to z~6 (Pearson, Wang, Hurley et al., 2018, submitted to A&A). We found that the normalisation of the SSR increases rapidly with redshift at z<~2, followed by a more gradual increase out to z~6. The evolution of the normalisation agrees well with the predictions from the Illustris simulation. Regarding the slope of the SSR, we found a continuous increase with redshift, with the slope approaching unity at high redshift which indicates galaxy formation is self similar in early epochs. Our forward modelling approach also allows us to probe the intrinsic width of the SSR, which we find to be around 0.2 dex, with a weak decreasing trend with increasing redshift.

Marianne Girard (Geneva Observatory)

Kinematics of low mass and/or low SFR galaxies at z~2 with the KMOS LENsing Survey (KLENS)

The KMOS/VLT Lensing survey (KLENS) is exploiting gravitational lensing to study kinematics of star-forming galaxies (SFGs) at 1.4<z<3.5 with low masses (median log(M_star/M_sun)=9.6) and/or low star formation rates (median SFR=6 M/yr). These SFGs are particularly interesting since they are Milky Way progenitors at high redshift. However, only few such objects have been analyzed at the moment since it is difficult to undertake the analysis of their morpho-kinematics without the help of lensing. The determination of the kinematic properties of these normal SFGs around the peak of the cosmic star formation rate density, would also allow us to determine how they differ from massive galaxies which have been analyzed so far.

We obtain that 25 to 40% of these low-mass/low-SFR galaxies are rotation dominated, which is significantly lower than surveys studying more massive galaxies. When combining our data with other surveys, we test the rotation dominated fraction dependance as a function of stellar mass, SFR, and offset from the main sequence. We find that the fraction of rotation dominated galaxies increases with the mass, and decreases for galaxies with a positive offset from the main sequence.

We also investigate the evolution of the intrinsic velocity dispersion as a function of the redshift and stellar mass assuming galaxies in quasi-equilibrium (Toomre Q parameter equal to 1). From the redshift-dispersion relation, we find that the redshift evolution for the velocity dispersion is mostly expected for massive galaxies. We derive a mass-dispersion relation which highlights that a different evolution of the velocity dispersion is expected depending on the mass. The observed velocity dispersions, while combining galaxies from many surveys, follow well this relation, except at high redshift (z>2), where we observe higher velocity dispersions for low masses (log(M_star/M_sun)~9.6) and lower velocity dispersions for high masses (log(M_star/M_sun)~10.9) than expected. Does it suggest that galaxies at high redshift do not satisfy the stability criterion (with the Toomre Q parameter different from 1)? Or that the adopted parametrisation of the sSFR and molecular properties fails at high redshift?

Xin Wang (Department of Physics and Astronomy, University of California, Los Angeles)

Precise evolution of gas-phase metallicity radial gradients at cosmic noon and its constraints on galaxy evolution

The chemo-structural evolution of galaxies at the peak epoch of cosmic star formation is a key issue in galaxy evolution physics that we do not yet fully understand. To address this, we investigate the spatial distribution of gas-phase metallicity in emission-line galaxies in the redshift range of z~1-3, i.e., at the cosmic noon. In a series of papers, we bring forward a novel method of obtaining sub-kpc resolution metallicity maps using space-based grism spectroscopy of strongly lensed galaxies. The sufficient spatial sampling, achievable only through the synergy of diffraction-limited data and lensing magnification, is crucial to avoid spuriously flat gradient measurements. Combining the deep HST/WFC3 near infrared grism data acquired by the GLASS project and a novel Bayesian method inferring metallicity from line fluxes directly, we obtained over 80 unbiased metallicity maps. This improves the number of such measurements at high redshift by one order of magnitude. Our maps reveal diverse galaxy morphologies, indicative of various effects such as efficient radial mixing from tidal torques, rapid accretion of low-metallicity gas, and other physical processes which can affect the gas and metallicity distributions in individual galaxies. We also observe an intriguing correlation between stellar mass and metallicity gradient, consistent with the ``downsizing'' galaxy formation picture that more massive galaxies are more evolved into a later phase of disk growth, where they experience more coherent mass assembly at all radii and thus show shallower metallicity gradients. Our techniques can also be applied to data from future space missions employing grism instruments, i.e., JWST, WFIRST, Euclid, etc.

Feng Yuan (Shanghai observatory)

Numerical study of AGN feedback in an elliptical galaxy

This talk will be based on our most recently finished a series of papers on AGN feedback. We investigate the effects of AGN feedback on the cosmological evolution of an isolated elliptical galaxy by performing two-dimensional high-resolution hydrodynamical numerical simulations. The inner boundary of the simulation is chosen so that the Bondi radius is resolved. Compared to previous works, two accretion modes, namely hot and cold, are properly discriminated; the feedback effects by radiation and wind in each mode are taken into account. The most updated AGN physics, including the descriptions of radiation and wind from the hot accretion flows and wind from cold accretion disks, are adopted. Physical processes like star formation, Type Ia and Type II supernovae are taken into account. The AGN light curve, typical AGN lifetime, growth of the black hole mass, AGN duty-cycle, star formation, and the X-ray surface brightness of the galaxy will be discussed.

Chiara Circosta (European Southern Observatory, Garching)

The SUPER survey: exploring the impact of outflows from active galactic nuclei with SINFONI and ALMA

Feedback from active galactic nuclei (AGN) is thought to influence the gas reservoir of galaxies through energetic outflows, whose impact is expected to be maximized at z~2 when the cosmic star formation history and the black hole accretion rate have their peak. However, a comprehensive study at this redshift is still missing. A key way to quantify the impact of AGN outflows on their host galaxies is to both investigate the properties of such outflows and for the same objects measure the molecular gas content. Our team is leading an ongoing Large Programme called SUPER (a SINFONI Survey for Unveiling the Physics and Effect of Radiative Feedback) targeting a representative sample of 40 AGN at z~2. It combines VLT/SINFONI observations (supported by adaptive optics capabilities) of the [OIII] emission line, to spatially resolve the ionized phase of outflows on galactic scales, and CO(3-2) observations with ALMA, which probe the amount of molecular gas in the host galaxies. I will compare the gas fraction of our AGN hosts with mass matched samples of inactive galaxies and further discuss if any gas depletion in the active galaxies is connected to on-going ionized outflows as traced by our SINFONI observations.

Fuyan Bian (European Southern Observatory, Chile)

Evolution of Ionized Interstellar Medium in Galaxies from High-z to Low-z

Ionized interstellar medium (ISM) provides essential information about the metal enrichment history, star formation environment, and underlying ionizing radiation field in galaxies. It is crucial to understand how the ionized ISM evolved with cosmic time. In this talk, I will present a method to select local galaxies that closely resemble the ionized ISM conditions in high-redshift galaxies. These local analogs of high-redshift galaxies provide unique local laboratories to study high-redshift galaxies. I will discuss how to use these galaxies to improve our understanding of the high-redshift metallicity calibrations and physical mechanism(s) to drive the evolution of star-forming galaxies on the optical diagnostics diagrams from high-z to low-z.