SESSION 1

Smit (invited)

An ALMA view of galaxies in the Epoch of Reionisation

In the past decade hundreds of galaxies have been identified in the Epoch of Reionisation, selected from their rest-frame UV light.
Only a handful of these sources, however, have spectroscopic redshift determinations and we have limited understanding of their physical properties.
ALMA is currently transforming this field by providing the first view of the dust obscured star-formation, the kinematics of these sources, the cool gas traced by [CII] and highly ionised gas traced by [OIII].
In this talk I will discuss new and recent results on the UV-bright galaxy population during the first billion years of cosmic time and what they imply for their observational and physical properties.

Finkelstein (invited)

Discovery of the Most Distant Star-Forming and Quenched Galaxies in the Universe

While the high-redshift component of the CANDELS survey was designed with the z~6-8 era in mind, these data do probe the far-UV of galaxies at even higher redshift. A few studies have ventured this far out, and have published conflicting results - some continue to find significant star-formation, while others conclude there is a steep decline in this quantity. I will report on a new search for z=9-10 galaxies, making significant use of the Spitzer/IRAC data in the CANDELS fields. We have discovered a larger number of galaxies in this epoch than previous works, implying the SFR density may be higher than previously thought. This implies that star-formation begins early in the universe. I will also report on a new study searching for the earliest quenched galaxies at $3 < z < 5$, which are not predicted by models, yet may exist if galaxies form very early, and thus can approach their quenching phase quicker.

Oesch

Galaxy Build-up at Cosmic Dawn: Insights from Deep Observations with Hubble, Spitzer, and ALMA

Over the last few years, great progress has been made in understanding the build-up of the first generations of galaxies based on deep optical and near-infrared imaging from the Hubble Space Telescope. However, HST only samples the rest-frame UV light of galaxies at z>=4, providing only limited information on the dust obscuration and on stellar masses of these sources. Fortunately, several Spitzer/IRAC programs have complemented the extragalactic HST fields with ultra-deep imaging data, allowing for a rest-frame optical view on early galaxies. Together with first ALMA/ NOEMA (sub)mm observations on distant galaxies, we are starting to gain a more and more complete picture of galaxy star-formation and mass build-up in the early universe. In this talk, I will present an overview of our current understanding of normal star-forming galaxies at z>3 based the combination of HST+Spitzer+ALMA/NOEMA data. In particular, I will show how HST as already pushed into JWST territory with the discovery and spectroscopic confirmation of a galaxy at z=11.1+-0.1, only ~400 Myr after the Big Bang. I will also highlight some of the exciting possibilities that lie ahead with JWST to push the spectroscopic frontier to the cosmic dawn and to finally probe the physics of early galaxies.

Hashimoto (invited)

Properties of galaxies at z = 6 - 9 revealed by ALMA

Understanding properties of galaxies in the epoch of reionization (EoR) is a frontier in the modern astronomy. With the advent of ALMA, it has become possible to detect far-infrared fine structure lines (e.g. [CII] 158 micron and [OIII] 88 micron) and dust continuum emission in star-forming galaxies in the EoR. Among these lines, our team is focusing on [OIII] 88 micron observations in high-z galaxies. After the first detection of [OIII] in the epoch of reionization (EoR) in 2016 from our team (z = 7.21; Inoue et al. 2016, Science 352, 1559), there are now more than ten [OIII] detections at z > 6 up to z = 9.1 (e.g. Hashimoto et al. 2018, Nature 557, 392; Tamura et al. 2019). Interestingly, high-z galaxies typically have very high [OIII]-to-[CII] luminosity ratio ranging from 3 to 12 or higher, demonstrating [OIII] is a powerful tracer at high-z. The high luminosity ratios may imply that high-z galaxies have low gas-phase metallicity and/or high ionization states. These ALMA observations also allow us to detect / place upper limits on dust continuum emission. Some z ~ 7 - 8 galaxies have dust continuum data at multiple wavelengths, allowing us to constrain the (luminosity-weighted) dust temperature. We show that z ~ 7 - 8 galaxies seem to have high dust temperature compared with the local Universe, probably due to strong UV radiation from massive and young stars. In addition to these ISM properties, we plan to present our detailed SED fitting results at z ~ 7 - 9 taking ALMA data into account, which are useful to infer the star formation history of these objects.

Bouwens

The Prevalence and Physical Properties of Extremely Low-Luminosity Galaxies in the Early Universe

Gravitational lensing from galaxy clusters has great potential for deriving the prevalence and phyical properties of ultra-faint galaxies at early times, with recent very impressive results from the Hubble Frontier Fields program. Important issues in deriving the most accurate results are accurate constraints on source sizes and a robust treatment of uncertainties in the magnification models. Using >3300 z=2-10 galaxies behind the 6 Hubble Frontier Fields clusters and a forwards modeling approach, I describe the efforts of my collaborators and me to map out the galaxy luminosity functions at ~-13 mag from z~9 to z~2, i.e, a factor of 1000 below L* and to the typical luminosity of galaxies suspected to drive cosmic reionization. Additionally, I discuss the constraints we can obtain on the properties of faint sources, in particular their stellar masses, mass-to-light ratios, colors, and stellar population ages. I conclude with a prospective on using cluster lenses to study the distant universe with the James Webb Space Telescope.

Bowler

Unveiling the nature of the brightest z > 6 galaxies with ALMA and JWST

The very brightest z > 6 galaxies are ideal laboratories for studying the physical properties of star-forming objects into the epoch of reionization. Selected from degree-scale, ground-based fields, these rare objects provide a key insight into early dust production and may harbour faint AGN. Targeted follow-up of small samples have unexpectedly shown both Lyman-alpha emission and other rest-frame UV lines (e.g CIV and HeII), suggesting unique star-formation conditions (or AGN) at early times. Furthermore, ALMA observations have revealed that 75% of the star-formation in these galaxies may be obscured. I will talk about HST/ALMA follow-up of bright z ~ 7 LBGs in COSMOS and present new results from even brighter samples from z = 6-9 selected over ~5 deg2. The power of both ALMA and JWST, coupled with the intrinsic luminosity of these sources, will provide a unique insight into the formation and evolution of vigorously star-forming galaxies in the first billion years.

Matthee

The hosts of early ionised bubbles: unveiling the most luminous Lyman-alpha emitters in the epoch of reionisation

Distant luminous Lyman-alpha emitters are excellent targets for detailed observations of galaxies in the epoch of reionisation. Spatially resolved observations of these galaxies allow us to simultaneously probe the emission from young stars, partially ionised clouds in the interstellar medium and to constrain the properties of surrounding hydrogen gas in the circumgalactic medium. In this talk specifically, I will focus on recent results from spectroscopic follow-up studies of luminous galaxies observed only ~500 Myr after the Big Bang with ALMA, HST/WFC3, and with MUSE and X-SHOOTER on the VLT. We find that these galaxies likely reside in early ionised bubbles and are complex systems, consisting of multiple well separated and resolved components where traces of metals and outflows are already present.

Atek

Probing the faintest galaxy population at the epoch of reionization with gravitational lensing

Ultra-deep observations of blank fields with the Hubble Space Telescope have made important inroads in characterizing galaxy populations at redshift z=6-10. Gravitational lensing by massive galaxy clusters offers a new route to identify the faintest sources at the epoch of reionization. In particular, thanks to the Hubble Frontier Fields program, we robustly pushed the detection limit down to MAB=-15 mag at z~6. I will present the latest results based on the complete dataset of the HFF clusters and parallel fields, and their implications on the ability of galaxies to reionize the Universe. I will also discuss the results of a comprehensive end-to-end modeling effort towards constraining the systematic uncertainties of the lens models, which are currently the last hurdle before extending the UV LF to fainter luminosities. Finally, I will discuss the great discoveries awaiting combination of such cosmic lenses with the upcoming James Webb Space Telescope and the exciting opportunity to probe the turnover of the UV LF, hence the limit of the star formation process at those early epochs.

Carniani

ALMA witnesses assembly of first galaxies

Characterising the primeval galaxies of the Universe entails the challenging goal of observing galaxies with modest star formation rates (< 100 Msun/yr) and approaching the beginning of the

reionisation epoch (z > 6). To date a large number of primeval galaxies have been identified thanks to deep near IR surveys. However, to further our understanding on the formation and evolution of such primeval objects, we must investigate their nature and physical properties through multi-band spectroscopic observations. Information on dust content, metallicity, interactions with the surrounding environment, and outflows can be obtained with ALMA observations of FIR fine structure lines such as the [CII] at 158 um and [OIII] at 88 um. ALMA observations reveal that the [OIII] and [CII] emission in z>5 star-forming galaxies are partly clumpy and partly diffuse on scales larger than 1kpc. Our analysis reveal that 9 out of 21 galaxies having ALMA [CII] detection break into multiple components and only a fraction of which, if any, are associated with the primary rest-frame UV components, while the bulk of the [CII] emission is associated with fainter rest-frame UV components, or not associated with any UV counterparts at the current limits at all. By taking into account the presence of all these sub-components, we found that the L[CII]-SFR relation in the early epoch has a dispersion two times larger than that observed in the local population. This dispersion reflects the heterogeneous properties of the primeval galaxies. We find that the [CII] luminosity is lower in high Lyα equivalent width (EW) sources than those with high Lyα EW, suggesting that the metallicity plays an important role on the [Cii] emission as also expected by recent simulations. The angular resolution of ALMA observations has also allow us to investigate the relation between [CII] surface brightness and star formation rate density.
Finally we discuss that the complex properties revealed by ALMA in z>5 galaxies are consistent with expectations by recent models and cosmological simulations, in which differential dust extinction, differential excitation and different metal enrichment levels, associated with different subsystems assembling a galaxy, are responsible for the various appearance of the system when observed with distinct tracers.

Renzini

Disentangling dwarf galaxies and forming globular clusters up to redshift about 10

Most very high redshift galaxies discovered so far are low mass dwarfs and their luminosity can be comparable to that of globular clusters forming at the same redshifts. A few such dwarfs and candidate globular cluster precursors have been resolved thanks to lensing but many more are expected to be found in the near future, especially with JWST which then will bring globular cluster formation in the early Universe an observational, as opposed to speculative science. This will include using clustering of globular cluster precursors as signposts of incipient massive galaxy formation as well as establishing whether forming globular clusters had a role in cosmic reionization. How observationally distinguish forming globular clusters from dwarf galaxies will then be discussed.

<u>SESSION 2</u>

Dayal (invited)

Early galaxy formation and its large-scale effects

Galaxy formation in the first billion years mark a time of great upheaval in the history of the Universe: the first galaxies started both the "metal age" as well as the era of comsic reionization. I will start by reviewing the dust production mechanisms and dust masses for high-redshift galaxies which will be revolutionized in the ALMA era. I will then show how the JWST will be an invaluable experiment to shed light on the impact of reionization feedback on early galaxy formation. As we look forward towards the era of 21cm cosmology, I will highlight the crucial and urgent synergies required between 21cm facilities (such as the SKA) and galaxy experiments (JWST, E-ELT and Subaru to name a few) to understand the physics of the epoch of reionization that remains a crucial frontier in the field of astrophysics and physical cosmology. Time permitting, I will try to give a flavour of how the assembly of early galaxies, accessible with the forthcoming JWST, can provide a powerful testbed for Dark Matter models beyond "Cold Dark Matter".

Narayanan (invited)

Dust in Galaxies across Cosmic Time

As a catalyst for H2 formation, regulator of interstellar temperatures, and significant source of opacity for UV/optical photons, dust plays a critical role in cosmological galaxy evolution. Yet, we know little about its formation, growth and destruction in galaxies across the mass spectrum from z=0 through the EoR. Here, I present a series of new cosmological simulations that self-consistently include these physical processes. Using these simulations, I will discuss the origin of dusty galaxies at high redshift, the dominant physics driving the evolution of the dust mass function across cosmic time, the impact of these physics on the observed dust to gas ratio in galaxies, and the impact on the dust size evolution and extinction and attenuation laws.

Wilkins

Understanding the early Universe with the BLUETIDES simulation

The formation of the first stars and super-massive black holes some few hundred million years after recombination brought an end to the cosmological dark ages. These early galaxies were likely responsible for reionizing the Universe, enriched their surroundings with heavy elements, and harboured the formation and growth of the first super-massive black holes. Providing insights into the physical processes shaping galaxy formation and evolution are fully hydrodynamical simulations which include both gravity and baryonic effects such as cooling, star formation, and feedback. The aim of the BLUETIDES project is to simulate a large enough volume at high-enough resolution to probe the formation of both galaxies and AGN in the early Universe. The core simulation has a resolution similar to EAGLE and Illustris but simulates a box almost 200 times larger. Consequently BLUETIDES simulates many more galaxies extending over a much wider mass range, thereby providing a much better match to existing and upcoming observational constraints. In addition to describing the overall project and some of the key insights I will also show forecasts for Webb, Euclid, and other upcoming facilities.

Arata

Galaxy evolution and radiative properties in the early Universe: multi-wavelength analysis in cosmological simulations

Recent observations have successfully detected galaxies in the epoch of reionization using UV and infrared bands, as well as emission lines. However, the origin of their radiative properties has not been understood yet. Combining cosmological hydrodynamic simulations and radiative transfer calculations, we present predictions of multi-wavelength radiative properties of the first galaxies at z=6-15. We find that most of gas and dust are ejected from star-forming regions by supernova feedback, which allows the UV photons to escape. We show that the peak of SED rapidly changes between UV and infrared wavelengths on a timescale of 100 Myr due to intermittent star formation and feedback. When dusty gas covers star-forming regions, the galaxies become bright in the observed-frame sub-millimeter wavelengths. We predict the detectability of high-z galaxies with the ALMA. In addition, we find that the escape fraction of ionizing photons also changes between 1-40 %.
The volume fraction of HII region changes intermittently, resulting in fluctuation of metal lines and Lyman-alpha line luminosities. In the starbursting phase of galaxies with halo mass 10^11 Msun (10^12 Msun), L_[OIII] ~ 10^41 (10^43) erg/s, which is consistent with observed star-forming galaxies at z>7. We predict that deep [CII] observatio by ALMA can trace distribution of neutral gas extending over ~20 physical kpc. Furthermore, the Lyman-alpha luminosity is ~10^40 erg/s and the equivalent width is > 30 angstrom, thus the galaxies may be detected by JWST as Lyman-Alpha Emitters. Our simulations show that the combination of multi-wavelength observations by ALMA and JWST reveal the multi-phase ISM structure and the transition from starbursting to outflowing phase of high-z galaxies.

Ceverino

FirstLight: Cosmological simulations of first galaxies at Cosmic Dawn

Cosmological hydrodynamical simulations have become an important theoretical tool for understanding the formation and evolution of the first galaxies during cosmic dawn, between redshifts 5 and 15. I will introduce the FirstLight database of about 300 zoom-in simulations with a resolution of 10 parsecs. This database agrees well with observed UV luminosity functions and stellar mass functions (Ceverino, Glover & Klessen 2017).
I will discuss the origin and evolution of the star-forming main sequence of galaxies and the main drivers of the star formation histories at these early epochs. (Ceverino, Klessen & Glover 2018).
I will show simulated SEDs from UV to IR (Ceverino et al. 2018), including stellar and nebular emission. The rest-frame UV spectra show steep slopes and a high production efficiency of Lyman continuum photons. These properties are consistent with young stellar populations with low metallicities. Simulated recombination lines allow us to link the physical conditions of the gas around these stellar populations with observables, like equivalent widths in OIII or Halpha or BPT diagrams at high-z. These simulations are making predictions that will be tested for the first time in future deep fields with the James Webb Space Telescope (JWST).
I will finally discuss preliminary results involving JWST mock fields and predictions for ALMA observations by post-processing FirstLight snapshots with Powderday radiative transfer code.

Ma

Understanding the formation of galaxies in the reionization era with realistic cosmological simulations

I will present a suite of high-resolution cosmological zoom-in simulations down to z=5, taking advantage of the realistic models of the multi-phase ISM, star formation, and feedback from the

Feedback in Realistic Environments (FIRE) project. With unprecedented details in these simulations, they are uniquely useful for predicting and understanding future observations. I will show how dust attenuation affects the UV properties of galaxies at z>5, including the shape of bright-end UV luminosity functions at these redshift, dust emission and temperature in the simulated galaxies, and how these results shed light on ALMA observations of dusty galaxies at z>5. I will also show the ubiquity of globular clusters in high-redshift galaxies, how these compact objects bias the measurements of faint-end UVLFs at these redshifts, and what we can improve with JWST.

Hutter

Shedding light on high-redshift galaxies with the 21cm signal

Reionization represents an important epoch in the history in the Universe, when the first stars and galaxies gradually ionize the neutral hydrogen in the intergalactic medium (IGM). Understanding the nature of the ionizing sources, the associated ionization of the IGM, and its impact on subsequent structure formation and galaxy evolution by means of radiative feedback effects, represent key outstanding questions in current astrophysics.
High-redshift galaxy observations and simulations have significantly extended our knowledge on the nature of high-redshift galaxies. However, essential properties such as the escape fraction of ionizing photons from galaxies into the IGM and their dependency on galactic properties remain essentially unknown, but determine significantly the distribution and time evolution of the ionized regions during reionization. Analyzing this ionization topology by means of the neutral hydrogen sensitive 21cm signal with radio interferometers such as SKA offers a complementary and unique opportunity to determine the nature of these first galaxies.
I will show results from a self-consistent semi-numerical model of galaxy evolution and reionization, and discuss the potential of inferring galactic properties with the 21cm signal as well as the impact of reionization on the high-redshift galaxy population and its evolution.

Naidu

New Constraints on Reionization from a Redshift-Independent Efficiency Model

We present an empirical model built on a high-resolution N-body dark matter simulation. We assume a redshift-independent star-formation efficiency for each halo to convert the accretion rate into a star-formation rate. Our model is calibrated using the z=4 UV luminosity function (UVLF) and successfully predicts the observed UVLF at z=5-10. We present predictions at z=5-10 for UV luminosity and stellar mass functions, JWST number counts, the stellar-to-halo mass relation and star-formation histories. We combine this model with bleeding-edge reionization constraints (from z>7 quasars, z~7 LyA line-profiles, the updated Planck Tau) to find new perspectives on the Epoch of Reionization (EoR). We find Muv<-13.5 galaxies need an average fesc=0.22+/-0.05 to drive reionization and a highly compressed timeline: the IGM neutral fraction is [0.9, 0.5, 0.1] at z=[8.4+/-0.2,7.0+/-0.2, 6.3+/-0.2]. Inspired by the newly assembled sample of Lyman Continuum leakers that unanimously displays higher-than-average star-formation surface density (sigma), we fit a model tying fesc to sigma. Since sigma grows by >2.5dex over z=0-8, our model explains the humble values of fesc at low-z. We find, strikingly, that <5% of galaxies with Muv<-18 account for >80% of the reionization budget. We predict leakers like COLA1 (z=6.6, Muv=-21.5) become common towards the EoR and that the protagonists of reionization are not hiding across the faint-end of the luminosity function but are already known to us.

SESSION 3

Charlot (invited)

A review of spectral energy distribution modeling at high-redshift

I will review recent developments in the modeling of high-redshift galaxy spectra, focusing in particular on the rest-frame ultraviolet and optical emission from young stellar populations and the interstellar medium.

Nanayakkara

A VLT/MUSE analysis of HeIIλ1640 emitters at z=2-4

In the quest to study early star-formation physics in the universe, one of the most sought after tracers is HeIIλ1640, with its presence in the lack of other metal emission/absorption lines generally being interpreted as evidence for metal-poor stellar populations. HeII ionizing photons are produced via sources of hard ionizing radiation and requires photons with energies >=54.4eV, however, traditional stellar population models lack sufficient ionising photons to match with current observations.
Our analysis of z=2-4 HeIIλ1640 emitters from deep 10-30h pointings from MUSE has shown that ISM properties inferred from multiple rest-UV diagnostics are not compatible with requirements necessary to reproduce HeIIλ1640 equivalent-widths. Thus, we have used latest generation of single, rotational, and binary stellar population models with realistic dust physics to explore rest-UV emission line diagnostics and link with H and He+ ionisation photon production efficiencies (ξion(H,He+)) in a variety of stellar/gas metallicities and star-formation histories. I will discus our latest results and show that including `exotic` stellar phenomena such as extreme low-metallicity binary stars, X-ray binaries, and dust dissociation physics may be necessary to lessen the tension between models and observations.

Schaerer

New insight on the far-UV SED and HeII emission from low metallicity galaxies

Understanding the ionizing spectrum of galaxies low-metallicity galaxies is of great importance for modeling and interpreting emission line observations of early/distant galaxies. Although a wide suite of stellar evolution, atmosphere, population synthesis, and photoionization models, taking many physical processes into account now exist, all models face a common problem: the inability to explain the presence of nebular HeII emission, which is observed in many low metallicity galaxies, both in UV and optical spectra. Several possible explanations have been proposed in the literature, including Wolf-Rayet stars, binaries, very massive stars, X-ray sources, or shocks, However, none has so far been able to explain the major observations.
We will present a simple and consistent physical model successfully explaining the observed trends and strength of nebular HeII emission in large samples of low metallicity galaxies and in individual galaxies, which have been studied in detail and with multi-wavelength observations.

Finally, we will discuss implications for the modeling and observations of the SEDs and emission line spectra of galaxies in the early Universe.

Stanway (invited)

Interpreting galaxy properties with improved modelling

Observations of star-forming galaxies in the distant Universe are starting to confirm the importance of massive stars in shaping galaxy emission and evolution. Distant stellar populations are unresolved, and the limited data available must be interpreted in the context of stellar population models. Understanding these populations, and their evolution with age and heavy element content is likely to be key to interpreting processes such as supernova and gamma-ray burst rates, cosmic reionization and the chemical enrichment of the Universe through galaxy-scale winds. With the upcoming launch of JWST and the promise of observations of galaxies within a billion years of the Big Bang, the uncertainties in modelling massive stars - and in particular their interactions with binary companions - are becoming increasingly important to our interpretation of the high redshift Universe. In turn, these observations of distant stellar populations will provide ever stronger tests against which to gauge the success of, and flaws in, current massive star models. I will review the current status of such models with a focus on binary stellar population synthesis.

Hopkins

Measuring the stellar initial mass function

The birth of stars and the formation of galaxies are cornerstones of modern astrophysics. While much is known about how galaxies globally and their stars individually form and evolve, one fundamental property that affects both remains elusive. This is problematic because this key property, the stellar initial mass function (IMF), is a key tracer of the physics of star formation that underpins almost all of the unknowns in galaxy and stellar evolution. It is perhaps the greatest source of systematic uncertainty in star and galaxy evolution. The past decade has seen a growing number and variety of methods for measuring or inferring the shape of the IMF, along with progressively more detailed simulations, paralleled by refinements in the way the concept of the IMF is applied or conceptualised on different physical scales. This range of approaches and evolving definitions of the quantity being measured has in turn led to conflicting conclusions regarding whether or not the IMF is universal. Here I summarise the growing wealth of approaches to our understanding of this fundamental property that defines so much of astrophysics, and highlight the importance of considering potential IMF variations, reinforcing the need for measurements to quantify their scope and uncertainties carefully. I present a new framework to aid the discussion of the IMF and promote clarity in the further development of this fundamental field.

Leja

An Older, More Quiescent Universe from Panchromatic SED Fitting of the 3D-HST Survey

Galaxy observations are influenced by many physical parameters: stellar masses, star formation rates (SFRs), star formation histories (SFHs), metallicities, dust, black hole activity, and more. As a result, inferring accurate physical parameters requires high-dimensional models which capture or marginalize over this complexity. We re-assess inferences of galaxy stellar masses and SFRs using the 14-parameter physical model Prospector-α built in the Prospector Bayesian inference framework. We fit the photometry of 58,461 galaxies from the 3D-HST catalogs at $0.5<z<2.5$. The resulting stellar masses are ~0.1−0.3 dex larger than the fiducial masses while remaining consistent with dynamical constraints. This change is primarily due to the systematically older SFHs inferred with Prospector. The SFRs are ~ 0.1 − 1+ dex lower than UV+IR SFRs, with the largest offsets caused by emission from “old” (t > 100 Myr) stars. These new inferences lower the observed cosmic star formation rate density by ~ 0.2 dex and increase the observed stellar mass growth by ~ 0.1 dex, finally bringing these two quantities into agreement and implying an older, more quiescent Universe than found by previous studies at these redshifts. We corroborate these results by showing that the Prospector SFHs are both more physically realistic and are much better predictors of the evolution of the stellar mass function. Finally, we highlight examples of observational data which can break degeneracies in the current model; these observations can be incorporated into priors in future models to produce new & more accurate physical parameters.

Hirschmann

Synthetic nebular emission lines of simulated galaxies in the early Universe

We present a detailed analysis of synthetic optical and UV emission lines of simulated galaxies out to the epoch of re-ionisation. The theoretical strong emission lines are derived from self-consistently coupling \new-generation\" spectral models accounting for nebular emission from both young stars and AGN to new sets of high-resolved cosmological hydrodynamic zoom-in simulations of young galaxies as well as to the IllustrisTNG simulation. Investigating the evolution of optical line-ratios in the BPT diagrams, we find that the simulations can successfully reproduce the observed trend that for a given [NII]/Halpha ratio, the [OIII]/Hbeta ratio is increasing towards high redshifts as a consequence of increased SFRs in young galaxies. Standard selection criteria in the classical BPT diagrams can appropriately differentiate simulated star-forming galaxies, galaxies dominated by AGN and composite galaxies at low redshits, but they fail to distinguish the main ionising source(s) in metal-poor galaxies, which dominate in the early Universe. To robustly classify the ionising radiation of such metal-poor galaxies, we propose 11 novel diagnostic diagrams based on equivalent widths and luminosity ratios of UV lines. We additionally highlight the multifaceted imprint of AGN feedback in projected 2D nebular emission line maps of massive, high-redshift galaxies, such as (i) central Ha deficiencies, reduced extent of Ha emission, and (ii) flattened [NII]/Ha gradients of high-redshift galaxies. Our novel interface between simulations and observations is potentially important for the interpretation of high-quality spectra of very distant galaxies to be gathered by next-generation telescopes, such as the James Webb Space Telescope.

Gomes

FADO: a novel self-consistency spectral population synthesis tool for the exploration of galaxy evolution at high redshift

Despite significant progress over the past decades, all state-of-the-art population synthesis (PS) codes suffer from deficiencies limiting their potential of gaining sharp insights into the star

formation history (SFH) and Chemical Enrichment History (CEH) of star-forming galaxies, i.e. the neglect of nebular continuum and, the lack of a mechanism to ensure consistency between the best-fitting SFH and the observed nebular characteristics (ONC; Balmer-lines, Balmer/Paschen jumps). These introduce biases in their recovered physical properties (stellar mass M* and sSFR). FADO is a novel self-consistent PS code employing genetic optimization, publicly available (http://www.spectralsynthesis.org), capable to identify the SFH & CEH that reproduce the ONC of a galaxy, alleviating degeneracies in the spectral fits.
The current version of FADO (V1.B) uses standard BPT emission-line ratios for the classification of low redshift (z) galaxies. Whereas this permits a reliable distinction between star-forming, Composite, Seyfert and LINERs, it is inapplicable to many high-z galaxies. We present an adaptation of FADO (version V1.C) to classify high-z galaxies employing the \Blue Diagram\" (e.g. Lamareille et al. 2010) for which the most prominent blue emission-lines (<~[OIII]5007) are observable while the Halpha and [NII] are inaccessible. FADO V1.C was applied to synthetic spectra simulating the evolution of galaxies formed at higher-z with different SFHs. FADO can recover the physical and evolutionary properties of galaxies, such as M* and mean age/metallicity, with an accuracy significantly better (~0.2 dex) than purely-stellar codes. An outline of FADO V1.C and applications to local and higher-z galaxies will be presented.

Curtis Lake

Modelling the mass-SFR relation at high redshifts; predicted constraints from JWST

The mass-SFR relation of galaxies encodes information of present and historical star formation in the galaxy population. We expect the intrinsic scatter in the relation to increase to low mass where SFR becomes more stochastic. Measurements at z>~4 from the Hubble Frontier fields have hinted at this (Santini et al. 2017), however, with the added uncertainty of lensing magnification we await JWST to provide robust measurements. Even with data-sets provided by JWST, uncertainties on mass and SFR estimates are often large, potentially covariant and dependent on assumptions used. I will present our method of Bayesian hierarchical modelling of the mass-SFR relation that self-consistently propagates uncertainties on mass and SFR estimates to uncertainties on the mass-SFR relation parameters. I will expose the biases imposed by standard SED-modelling practices, and address to what significance we can measure an increase in intrinsic scatter to low masses with JWST.

Stefanon

Star-formation efficiency at 600 Myr of cosmic time

In the last decade, the increased sensitivity of HST/WFC3 combined with Spitzer/IRAC coverage have enabled the identification of about 700 galaxies at z>7. These observations suggest an accelerated evolution of the cosmic star formation rate density for 8<z<10, indicating that galaxy assembly experienced an extremely intense phase during the first ~600Myr years of cosmic time. However, while we have a fair understanding of the gravitational assembly of the dark matter halos which drive the accretion of cold gas, the baryonic processes controlling the transformation of gas into stars are still largely unknown. Observations of galaxies at high redshifts offer a unique opportunity to directly probe young (unresolved) stellar population at early cosmic epochs, and the efficiency of star formation (SFE). Here we will present our recent observations of spectral energy distributions of star-forming galaxies at z~8, just ~600Myr after the Big Bang. Leveraging the deepest Spitzer/IRAC data available (rest-frame optical), we find extremely intense nebular line emission (EW0(Ha)>~1000AA), high specific star-formation rates (~10/Gyr) and indication of an inverse Balmer break (Balmer jump) generated by the nebular continuum emission. These results point towards very young ages (<100Myr), and, combined with measurements at lower redshifts, that the SFE evolved only marginally during the first ~1.5Gyr of cosmic history. We will conclude presenting our recent results on the search and characterization of ultrabright star-forming galaxies at z~8 over the COSMOS/UltraVISTA survey, key systems for testing our current understanding of galaxy formation (e.g., GN-z11, Oesch et al., 2016).

SESSION 4

Bañados (invited)

The most distant quasars and their environments

The number of quasars known within the first billion years of the universe (z>6) has increased significantly over the last five years. Many of these recently discovered quasars are ideal targets for observatories in the southern hemisphere such as ALMA. I will review the current status of the highest-redshift quasars and their environments, highlighting main achievements and limitations. I will then discuss how synergistic JWST/ALMA observations will shed light onto the properties and formation of some of the most extreme environments in the early universe.

Fan

A Rapidly Evolving Quasar Population at the Epoch of Reionzation

I will present results from our on-going large area survey of high-redshift quasars, which has discovered more than 20 new quasars at z>6.5, at the epoch of reionziation, forming the first large statistical sample of EoR quasars. I will discuss the rapid evolution of quasar density at that epoch, which suggests that we are witnessing the emergence of the first supermassive black hole population. I will also present multiwavelength followup observation results, especially from ALMA and Chandra, which reveals a diverse environment of quasar activities and yields new insights into the supermassive black hole/massive galaxy co-evolution.

Venemans

Illuminating the Dark Ages: Luminous Quasars and their Massive Host Galaxies in the Reionization Epoch

Quasars are the brightest, non-transient objects observed at the highest redshifts, z>7, which makes them unique probes of the evolution of black holes, massive galaxies and the intergalactic medium: the density of high redshift quasars puts powerful constraints on the mechanisms that are required to seed and grow supermassive, >10^9 solar mass black holes less than a Gyr after the Big Bang. Observations in the (sub)millimeter can constrain the gas and dust content, star formation rate and masses of the galaxies hosting these luminous quasars. In this talk I will present the results of various multi-wavelength follow-up programmes of the most distant quasars currently known, focussing on our recent ALMA observations of the quasar host galaxies at z~7 and discuss the implications of the findings on massive galaxy formation, the black hole - galaxy coevolution and cosmic reionisation.

Alberts

Probing the supermassive black hole growth-galaxy assembly connection in radio populations at cosmic noon

Multiple lines of evidence point to a strong connection between galaxy assembly and supermassive black hole (BH) growth, processes which both peak around cosmic noon (z~1-3). Understanding this connection is key to galaxy evolution studies and timely, as JWST will soon provide new insights into the origin of the BH-bulge relation and the role of AGN in reionization in the early Universe.

In this talk, I will present new results leveraging ultra-deep (<0.4 uJy/beam rms), high resolution (<0.7\) 3GHz and 6GHz VLA imaging against the unique X-ray and optical/IR imaging in the Hubble Ultra-Deep Field (HUDF) to quantify AGN in radio-selected galaxies. Deep, high resolution radio imaging provides a powerful dataset, localizing non-thermal continuum to sites of star formation and/or AGN. By utilizing all available AGN tracers (e.g. X-ray, UV-IR SED decomposition, radio-IR correlation), I will present a constraining picture of unobscured and obscured BH growth in radio galaxies at cosmic noon. I will discuss radio properties (luminosity, morphology, spectral slope) of multiwavelength-identified AGN, and tie in galaxy properties such as star formation and resolved stellar mass maps. I will touch on the radio spectral slope at z~1-3 for the full sample, which is steeper on average than expected from local studies. Lastly, I will discuss the synergy between VLA and JWST in resolving outstanding questions about the galaxy-AGN connection throughout cosmic time, highlighting our planned Cycle 1 JWST/MIRI HUDF survey designed to perform an in-depth analysis of a complete sample of AGN and their hosts.

Bischetti

Uncovering QSO-driven outflows and galaxy assembly at cosmic Dawn with ALMA

I will present evidence of QSO-driven outflows in the early Universe, resulting from the stacking analysis of ALMA observations of the [CII] emission line for a sample of 50 QSOs at z~5-7. The high sensitivity reached by our analysis allowed us to assess that very broad wings are on average present in the [CII] profile, and extend beyond velocities of 1000 km/s in systems with low and high SFR. Such wings are therefore tracing QSO-driven [CII] outflows, with associated mass outflow rates of 100-200 Msun/yr. I will discuss how these outflows relate to those observed in lower-z AGNs and give an estimate of their spatial extent. Furthermore, I will focus on the high-resolution ALMA observation of a hyper luminous QSO at z~4.5, revealing an exceptional overdensity with multiple companions as close as 2 kpc. These crowded surroundings, and the QSO host galaxy itself, are forming stars at a very high rate (hundreds of Msun/yr), suggesting that a significant fraction of the stellar mass assembly at early epochs might have taken place in the companions. I will discuss how the BH and host-galaxy masses are growing in this multi-source system, which likely represents the cradle of what would be a giant galaxy at z = 0.

Izumi

Rapid evolution and transformation into quiescence?: ALMA view on z > 6 low-luminosity quasars

I will report our ALMA observations toward seven z > 6 optically low-luminosity quasars (M_1450 > -25).
These quasars were discovered by our on-going deep optical survey with the Hyper Suprime-Cam (HSC) on Subaru telescope.
We found with [CII] and rest-FIR continuum emissions that the galaxies hosting these HSC quasars typically show LIRG-class star-forming properties (SFR ~ several x 10 Msun/yr). These values are smaller than those of SDSS-class quasars by 10 times or more, thus we are exploring a totally different parameter-space from previous studies. Using the [CII] dynamics and our NIR spectroscopic data, we found that the ratios of their SMBH masses and dynamical masses are consistent with the local value of co-evolution. Furthermore, our faint quasar hosts are on or even below the star-forming main sequence at z ~ 6; i.e., they appear to be transforming into quiescent galaxies after completing major evolutionary phases. Our ALMA works suggest a quite rapid galaxy evolution even at z > 6 and encourage us (1) to measure stellar mass content of their hosts and (2) to hunt for their descendants, likely compact stellar galaxies, at z ~5-6 with JWST.

Juneau (invited)

The AGN-Galaxy Connection: Low-Redshift Benchmark & Lessons Learnt

Several scenarios have been proposed to describe the physical connection between galaxies and their central AGN. This connection could act on a range of spatial scales and vary across cosmic time. So far, different results have been obtained for various galaxy and/or AGN selection methods, which emphasizes the need to understand sample selection. We have revisited AGN classification using a combination of emission-line diagnostic diagrams, and we found interesting trends on the star formation rate - stellar mass (SFR-M) plane. In particular, we find that the most likely connection is that star formation and AGN share a common gas reservoir, and are both declining in parallel as the gas reservoir is consumed. While there could be exceptional cases (e.g., galaxies in major mergers), the overall trend supports previous results suggesting that most star-forming galaxies undergo a slow quenching. Our interpretation is also supported by comparisons with the MAGNETICUM cosmological simulations, which include AGN growth and feedback, as well as emission-line signature predictions. Additionally, this work represents a low-redshift benchmark against which to compare higher redshift studies. We have incorporated statistical incompleteness corrections for both the parent sample selection and for emission-line selection criteria, which can act as lessons to keep in mind as we keep pushing the limits toward higher redshifts.

Umehata

Active dust-obscured star-formation at a z=3 proto-cluster

Galaxies and nuclei in the dense environment at high redshift provide a good laboratory to investigate the accelerated, most extreme evolution of galaxies at a given epoch. SSA22 field has known to have a 50 (comoving) Mpc-scale cosmic structure, which makes the field a suitable target in this regards. To identify dust-obscured star-formation, a contiguous 20 arcmin^2 regions at the node were observed by ALMA band 6. About 7 arcmin^2 region has 1sigma sensitivity of 25uJy/beam, while the remaining ~13 region has 1sigma 60 uJy/beam at 1.14mm. In total 57

ALMA sources have been identified above 5sigma (and much more below 5sigma with caution), which makes the field one of the richest field of ALMA-identified submillimeter galaxies. The follow-up spectroscopy confirmed about 20 sources as exact proto-cluster members so far. Together with high X-ray AGN fraction, our results suggest that the vigorous star formation activity and the growth of super massive black holes (SMBHs) occurred simultaneously in the densest regions at z~3. Abundant gas fueling from cosmic web is suggested from co-spatial mosaic observations of ALMA band 3 and MUSE survey. We may be seeing the most active historical phase of the massive galaxy population found in the core of the clusters in the present-day universe.

Sharon

More than Star Formation: The High-J CO SLEDs of High-z Galaxies

Theoretical work suggests that AGN play an important role in quenching star formation in massive galaxies. In addition to molecular outflows observed in the local universe, emission from very high-J CO rotational transitions has been one of the key pieces of evidence for AGN directly affecting the molecular gas reservoirs that fuel star formation. However, very few observations exist of CO rotational lines past the peak of the CO spectral line energy distribution (SLED) for galaxies in the early universe. Here we will present new ALMA observation of high-J CO rotational lines (CO(10-9) through CO(17-16)) in six z>2 IR-bright AGN host galaxies. We will discuss the excitation mechanisms for these lines, the fraction of these galaxies\' molecular gas impacted by the AGN, and how that might affect their star formation.

<u>SESSION 5</u>

Aravena (invited)

The ISM content of galaxies in the ALMA era

The advent of ALMA has enabled a new era for studies of the formation and assembly of distant galaxies. Large surveys of the cold dust continuum and molecular gas line emission have flourished in the last few years, covering different galaxy properties and redshift ranges, and allowing us to have better insights into the physical mechanisms behind the galaxy growth. In this talk, I will present a brief overview of some of the recent studies that aim to characterize the ISM properties of galaxies at high redshift (e.g. z>1). In particular, I will focus on studies conducting dust continuum and molecular line emission “deep field” observations, including recent results from the ALMA Spectroscopic Survey in the Hubble Ultra Deep Field (ASPECS) large program.

Spilker (invited)

Fueling, Star Formation, and Quenching Revealed by High-Resolution Imaging and Gravitational Lensing

The completion of ALMA has led to the ability to make observations with unprecedented resolution at submm wavelengths, allowing novel probes of the ISM and kinematics of high-redshift galaxies. Because they are magnified by foreground galaxies or clusters, gravitationally lensed galaxies allow the highest possible spatial resolution to be obtained, and/or a sharp reduction in the observing time required to detect faint objects or spectral lines. These benefits have made lensed galaxies useful benchmark systems for ALMA, enabling a wide variety of science cases from dense gas tracers to <~100pc maps of galaxies in the first billion years. I will give a brief overview of highlights obtained through the study of high-redshift lensed galaxies. In particular I will focus on novel spectral probes that allow us the first detailed look at galactic feedback processes in the early universe, enabling the first resolved maps of galactic winds that are likely responsible for many of the most fundamental correlations in galaxies. I will end by highlighting the revolutionary prospects enabled by the combination of JWST and ALMA observations, including the chance to take a full census of galactic outflows in multiple gas phases at matched spatial resolution.

Williams

Understanding the formation of massive quiescent galaxies at z>1: measuring their cold ISM properties with ALMA and future prospects with JWST

Quiescent galaxies are the remnants of both rapid star-formation in the early Universe, and powerful feedback mechanisms that may truncate star-formation. Understanding these processes are major goals for both ALMA and JWST. I will present new results of an ALMA program to measure the molecular gas properties and star-formation efficiency in 7 massive, spectroscopically confirmed quiescent galaxies at z>1. These data are deep and provide the most stringent constraints on gas fraction (to date), putting strong limits on the role of dynamical regulation or extreme feedback in truncating star-formation. Our results complement observations of local post-starburst galaxies, some of which contain significant molecular gas reservoirs, and extend constraints on cold gas content in quenching galaxies out to the peak quenching epoch at z~2. Collectively, these observations highlight a diversity in molecular gas properties among quenching galaxies, which our theoretical formulations of quenching processes must accommodate. I will conclude by discussing how JWST surveys in combination with ALMA will resolve outstanding questions about the formation of quiescent galaxies in the early Universe. In particular, I will show science predictions out to z~15 for JWST Cycle 1 using JAGUAR, a new analysis package that produces mock JWST observations. JAGUAR is available for download to facilitate GO Cycle 1 proposal planning, and will serve as a powerful future JWST data analysis tool after launch.

Suess

ALMA reveals large molecular gas reservoirs in recently-quenched galaxies

We still do not understand the physical mechanisms that are responsible for suppressing star formation in galaxies. Observations of post-starburst galaxies, whose spectra indicate that an intense period of star formation was followed by rapid quenching, are the ideal sample to probe the quenching process. We have conducted an ALMA survey of CO(2-1) in 13 of these recently-quenched galaxies at z~0.7 -- high enough redshift that these galaxies likely just concluded their primary epoch of star formation, but low enough redshift for follow-up observations to be feasible. Our observations reveal a stunning diversity of molecular gas properties: despite a uniform optical selection and low apparent SFRs, the detected galaxies span a factor of >30 in CO luminosity and have inferred gas fractions ranging from < 1% to 20%. These observations indicate that quenching does not require the total removal or depletion of molecular gas. No current models of the quenching process can fully explain our results.

Falgarone

Large turbulent reservoirs of cold diffuse gas unveiled with CH+(1-0) lines around high-redshift starburst galaxies

Starburst galaxies at redshift z ~ 2–3 are among the most intensely star-forming galaxies in the universe. How do they accrete their gas to form stars at such high rates is still a controversial issue. We report ALMA detections of CH+(1-0) emission and absorption lines from twelve gravitationally lensed starburst galaxies at redshifts between 1.6 and 4.2 with star-formation rates in the range 300–1400 $M_{\odot}$ yr^{-1}. The unique conjunction of its spectroscopic and chemical properties allows CH+ to highlight the sites of most intense dissipation of mechanical energy. The absorption lines reveal highly turbulent reservoirs of low-density molecular gas, extending far out of the galaxies. The emission lines, with linewidths, up to 1400 km s^{-1}, much broader than those of CO, arise in myriad shocks powered by star formation and possibly active galactic nuclei. The CH+ lines therefore probe the fate of prodigious energy releases, primarily stored in turbulence before being radiated away. The turbulent reservoirs act as sustained mass and energy buffers over timescales up to a few hundreds of Myr. Their mass supply is likely to involve galaxy mergers and/or cold stream accretion.

Magdis

An Inventory of Molecular Gas Tracers Across Cosmic Time

One of the major challenges in the studies of galaxy evolution remain is to determine the gas mass reservoir of galaxies and its evolution with cosmic time.
In this talk I will combine results from our recent ALMA and IRAM programs that target star-forming galaxies from z=0.0 to z=6, and present scaling relations between various observables and the molecular gas mass of the galaxies, ranging all the way from mid-IR PAH features to [CI], C+, CO far-IR lines and mm continuum flux densities.
I will discuss how these universal scaling relations can serve as tools to measure the ISM content of galaxies in the early universe and provide a better picture of the role of gas in galaxy evolution since the epoch of re-ionisation.
Among others, the new observations include:
- a large ALMA [CI] survey of ~50 z~1 normal star-forming galaxies,
- CI[1-0] and CI[2-1] observations of a template star-bursting galaxy at z=4.0 (GN20),
- [CII] observations of normal z~2 star-forming galaxies as well as
- CO and mm continuum observations of intermediate redshift ULIRGs, z~3 LBGs and z>4 HST dark starbursting galaxies.

Le Fevre

The ALMA ALPINE [CII] survey of 122 normal star-forming galaxies at 4<z<6

ALPINE is a Large Program with ALMA which focuses on measuring the gas (from [CII]) and dust properties (from continuum) of a large sample of 122 normal main-sequence galaxies at 4<z<6.

The main goals at this epoch are (1) to follow the evolution of the total star formation, (2) To explore the reliability of [CII] as an SFR indicator , (3) To measure the dust content, (4) To follow the evolution of the gaz fraction. After the completion of the observations early 2019, and matching with all available multi-wavelength information, I will present the general sub-mm properties of the sample in [CII] and continuum, and report on the first reliable estimates of the [CII] luminosity function, dust content, gas fraction, and total SFRD, at an epoch right after the end of HI reionization.

Shivaei (invited)

Optical and near-IR studies of the ionized gas and dust during the peak epoch of cosmic star formation activity

ISM is composed of multiple components, including molecular, neutral, and ionized gas, large dust grains in thermal equilibrium with their surrounding, and small dust grains, such as PAHs, heated by single photons. The different components of ISM are related to each other mainly through star formation — some are fuel for star formation (molecular gas) and some are the products of it (ionized gas, dust). Therefore, to fully understand the physics of star formation and its evolution throughout cosmic time, it is crucial to measure and observe different ISM components of galaxies out to high redshifts. I will review the current status of optical and near-IR studies of ionized gas and dust in galaxies during the peak epoch of star formation activity (z~1-3). With the advent of multi-object near-IR spectrographs on 10-m-class telescopes, we are now able to construct large rest-optical spectroscopic samples of galaxies at z~1-3. Using optical emission lines, we measure dust extinction towards ionized gas, gas-phase abundances, electron densities, ionization and excitation state of the gas, and AGN contribution in galaxies at z~1-3. By incorporating other UV-to-IR ancillary data, we study the physical processes that lead to relations between mass, gas-phase metallicity, SFR, and dust content of high-redshift galaxies. JWST will advance such studies by probing lower luminosities and higher redshifts, owing to its significantly higher sensitivity. Incorporating ALMA observations of cold dust and molecular gas at z>1 will give us a nearly complete picture of the ISM in high-redshift galaxies over a large dynamic range in mass.

Liu

The Cosmic Evolution of Cold Gas from A3COSMOS: New Constraints and Systematic Biases from ~1000 Galaxies at z~1-6

A galaxy's cold gas reservoir determines the rate at which it can be forming stars. Therefore measuring the cosmic evolution of the cold gas mass of galaxies is critical to our understanding of galaxy evolution. Obtaining such measurements for large samples of galaxies at z~1-6 is challenging even in the ALMA era. Recent studies of the cosmic gas evolution go up to only z~3 and show significant differences. As the (sub-)millimeter dust continuum has now been established as reliable tracer by several studies, we have started a concerted effort to exploit the public ALMA archive data in the COSMOS field, in a coherent, systematic way to quantify systematic biases in using dust continuum to infer cold gas mass and determining cosmic gas evolution. Our project A3COSMOS (Auto-mining the ALMA Archive in COSMOS) currently includes ~2000 ALMA images covering 280 sq. arcmin with over 1500 high-confidence (spurious fraction <10%) ALMA detections based on well-characterized statistics. Using the rich ancillary data we identify ~1000 galaxies with bona-fide properties lying at z~1-6. We quantify systematic biases presented in this large sample and previous works, as well as their effects on the determination of the cosmic evolution of cold gas. This includes an optimized treatment of the dependence of stellar mass and dust-to-gas ratio on metallicity for large datasets at various redshifts. We present for the first time a well-characterized cosmic cold gas evolution measurement out to z~6. Further we find that proper accounting for biases can significantly reduce differences between studies.

Romano

13C/18O ratio as a litmus test of stellar IMF variations in high-redshift starbursts

Determining the shape of the stellar initial mass function (IMF) and whether it is constant or varies in space and time is the Holy Grail of modern astrophysics, with profound implications for all theories of star and galaxy formation. On a theoretical ground, the extreme conditions for star formation (SF) encountered in the most powerful starbursts in the Universe are expected to favour the formation of massive stars. Direct methods of IMF determination, however, cannot probe such systems, because of the severe dust obscuration affecting their starlight. The next best option is to observe CNO bearing molecules in the interstellar medium at millimetre/submillimetre wavelengths, which, in principle, provides the best indirect evidence for IMF variations. In this contribution, we present our recent fi ndings on this issue. First, we reassess the roles of different types of stars in the production of CNO isotopes. Then, we calibrate a proprietary chemical evolution code using Milky Way data from the literature, and extend it to discuss extragalactic data. We show that, though signi cant uncertainties still hamper our knowledge of the evolution of CNO isotopes in galaxies, compelling evidence for an IMF skewed towards high-mass stars can be found for galaxy-wide starbursts. In particular, we analyse a sample of submillimetre galaxies observed by us with the Atacama Large Millimetre Array at the peak of the SF activity of the Universe, for which we measure 13C/18O ~ 1. This isotope ratio is especially sensitive to IMF variations, and is little affected by observational uncertainties. At the end, ongoing and future developments of our work are briefly outlined.

SESSION 6

Wutys (invited)

Resolved views of early galaxy evolution

Resolved observations of star-forming galaxies at cosmic noon with the Hubble Space Telescope and large ground-based facilities provide a view on the spatial distribution of stars, gas and dust, and probe gaseous motions revealing the central gravitational potential and local feedback processes at play. I will review recent insights gained from such observations, with an emphasis on results obtained through optical/near-infrared imaging and imaging spectroscopy. I will first consider the evolution of galaxies as axisymmetric systems and then discuss deviations from axisymmetry.

Rujopakarn (invited)

Sub-galactic views of cold gas and dust in distant star-forming galaxies: pushing the ~100 pc frontier at z ~ 3

While the evolution of spatially-integrated properties of galaxies are relatively well constrained across cosmic time, many of the most fundamental processes are not well understood, especially down to the sub-galactic scales, where frontier questions in galaxy evolution lie: How did galactic spheroids form? How did galaxies and their supermassive black holes co-evolve? With the angular resolution capability of ~tens of milliarcseconds, ALMA has conferred extinction-independent views of cold gas and dust distributions within individual z ~1-4 galaxies at resolutions approaching ~100 pc, thereby opening new avenues to study sub-galactic properties of galaxies at the peak of their assembly. In this talk, I will review recent findings and ongoing challenges enabled by ALMA's extinction-independent, spatially-resolved views of star forming galaxies, particularly the galactic substructures, e.g., clumps (or the lack thereof) from both field and gravitationally-lensed galaxies, and their implications on the bulge assembly scenario. I will also discuss a new synergistic approach between radio and millimeter observations (using, e.g., VLA and ALMA) to independently pinpoint the locations of star-forming region and AGN down to <100 pc at z ~ 3. Lastly, I will discuss the planned surveys with JWST in the first year of operation, and ways that the first datasets can be combined with ALMA to provide new breakthroughs and plan future observations to utilize Webb to the fullest.

Bezanson

Spatially resolving the relics: The inferring the physics driving the quenching of massive galaxies from kinematics at z~1 and beyond

Today's massive elliptical galaxies are primarily red-and-dead, dispersion supported ellipticals. The physical process(es) driving the shutdown or "quenching" of star formation in these galaxies remains one of the least understood aspects of galaxy formation and evolution. Although today's spiral and elliptical galaxies exhibit a clear bimodality in their structures, kinematics, and stellar populations, it may be that the quenching and structural transformation do no occur simultaneously. In this talk I will present evidence that early quiescent galaxies, observed much closer to their quenching epoch at z~1, retain significant rotational support (~twice as much as local ellipticals). This suggests that the mechanisms responsible for shutting down star formation do not also have to destroy ordered motion in massive galaxies; the increased dispersion support could occur subsequently via hierarchical growth and minor merging. I will discuss this evidence in conjunction with recent ALMA studies of the dramatic range in molecular gas reservoirs of recently quenched high redshift galaxies to constrain quenching models. Finally, I will discuss prospects for extending spatially resolved spectroscopic studies of galaxies immediately following quenching with JWST and eventually 30-m class telescopes.

James

Mapping the Structure and Source of Outflows from Star-forming Galaxies at z=2-3

As we enter the era of JWST our need to characterise the rest-frame UV spectra of star-forming galaxies becomes essential. By combining the NIR capabilities of JWST with our understanding of UV wavelength science, we have the opportunity to explore fundamental properties of the gas, such as its metallicity and density, as well as the extent, velocity, and magnitude of their

outflowing gas, in galaxies out to z~6. Galaxy outflows in particular play a fundamental role in the evolution of young galaxies at high redshifts, but their properties remain largely unknown as it is difficult to spatially resolve the outflowing gas.
To-date, only two attempts to resolve outflows at redshift ~2 have been made using lensing magnification, producing contradictory results on the origin of the outflows.
In this talk I will present results from one such groundbreaking study where we combine gravitational lensing with VLT-MUSE to perform one of the first spatially resolved absorption line studies of a galaxy at z=2-3. I will discuss how the the distinct kinematical structure and uniform column densities obtained from the outflowing gas maps reveal \'global\' rather than \'locally\' sourced outflows. I will also present preliminary results from our latest attempt to accurately constrain the structure and source of outflows in star-forming galaxies by observing the brightest galaxy-scale lens known with KCWI.
I will conclude with the benefits and limitations of spatially resolved observations in this wavelength range, and possible implications on NIRSpec observations of the high-z Universe.

Dessauges

Molecular clouds in a Milky Way progenitor observed 8 billion years ago

Thanks to the remarkable ALMA capabilities and the unique configuration of the Cosmic Snake galaxy behind a massive galaxy cluster, we could, for the first time, resolve molecular clouds down to 30 pc linear physical scales in a typical Milky Way progenitor at z=1.036 through CO(4-3) observations performed at 0.15" angular resolution. We identify numerous (17) individual giant molecular clouds (GMCs) that occupy the 1.7 kpc central region of the Cosmic Snake galaxy. These high-redshift molecular clouds are clearly different from their local analogues: with radii between 30 to 210 pc, they are two orders of magnitude more massive (8x10^6-1x10^9 Msun), one order of magnitude denser (with a median molecular gas mass surface density of 2600 Msun/pc2), and on average more turbulent (with internal velocity dispersions of 9-33 km/s). They thus are offset from the Larson scaling relations, well established for the local GMCs, and challenge the universality of molecular clouds. We argue that GMC physical properties are dependent on the galactic environment: GMCs must inherit their physical properties from the ambient ISM particular to the host galaxy. We find these high-redshift GMCs in virial equilibrium, and derive, for the first time, the CO-to-H2 conversion factor from the kinematics of independent GMCs at z~1. The measured large clouds gas masses demonstrate the existence of parent gas clouds with masses high enough to allow the in-situ formation of similarly massive stellar clumps seen in the Cosmic Snake galaxy in a comparable number to the GMCs. The comparison of the GMC masses and star cluster masses suggests a high efficiency of star formation, which anchors at z~1 the recently proposed scaling of the star formation efficiency with gas mass surface density. Our results corroborate the formation of GMCs by fragmentation of distant turbulent galactic gas disks, which then turn into the stellar clumps ubiquitously observed in galaxies at cosmic noon.

Lang

Uncovering the spatial distribution of stars and dust in z~2 SMGs

The spatial distribution of the dust and stars contains crucial information about the evolutionary pathways of galaxies.

I will present results of our study combing high-resolution ALMA and HST observations of z~2 bright sub-millimeter galaxies (SMGs). We have developed a two-dimensional extinction and age correction technique to obtain accurate stellar mass distributions from HST/CANDELS. For the first time, we can directly compare the spatial distribution of assembled stellar mass and ongoing star formation on ~kpc scales for distant SMGs, sheding light on their formation mechanisms which are highly debated. Overall, we find that the dust distribution is more compact than the stellar component, regardless if the SMG lies on the main sequence or at the starburst regime. Taking dust emission as a proxy for dust-obscured star formation, our results imply that high-redshift SMGs are experiencing centrally enhanced star formation. We see tentative evidence that the surface density of star formation relative to stellar surface density increases with distance from the main sequence.
These findings suggests that major galaxy interactions are not necessarily the main formation channel for SMGs with secular disk formation remaining a viable option as suggested by state-of-the-art cosmological simulations. The sizes and stellar densities of our z~2 SMGs agree well with the most compact early-type galaxies in the local Universe, strongly supporting the idea that the latter systems are indeed descendants of massive SMGs at z~2.

Ritondale

Resolving on 100 pc-scales the UV-continuum in Lyman-emitters between redshift 2 to 3 with gravitational lensing

Lyman-alpha emitting (LAE) galaxies are thought to be predominantly responsible for the re-ionisation of the Universe and are, as such, one of the most studied star-forming galaxy populations. Current optical and narrow-band studies are limited by the angular resolution of the observations and the considerable investment in telescope time. Strong gravitational lensing is an extremely powerful method that can be used to overcome these limitations. In my talk I will present a study on the first homogeneous sample of 17 lensed Lyman-alpha emitters at redshift 2< z < 3. By taking advantage of the lensing magnification, I was able to access the detailed structure of this high redshift star-forming galaxies, finding that they have radii ranging from 0.2 to 1.8 kpc and have a complex and clumpy morphology, with a median ellipticity of 0.49. This is consistent with disk-like structures of star-formation, which would rule out models where the Lyman-alpha emission is only seen perpendicular to the disk, and favours those clumpy models for the escape lines of sight for Lyman-alpha photons. We also find that the star formation rates range from 0.3 to 8.5 M/yr and that these galaxies tend to be very compact. The lower limit to their intrinsic size is about a factor of two smaller than that found for non-lensed LAEs, which highlights the power of gravitational lensing and sophisticated lens modelling techniques for resolving such objects in the high redshift Universe.

Man

Lensed quiescent galaxies at z~2: what quenched their star formation?

A key outstanding issue in galaxy evolution studies is how galaxies quench their star formation. I will present new results from our VLT/X-Shooter, ALMA and VLA campaign of a pilot sample of lensed quiescent massive galaxies at z>1.5. Lensing magnification enables us to spatially resolve the stellar structure and kinematics of these compact galaxies, that are otherwise barely resolvable even with HST. Our deep X-Shooter spectra provided multiple absorption lines enabling strong constraints on their stellar populations, namely their star formation rates, ages, dispersions, and in some cases metallicities. Our complementary ALMA+VLA programme probes their molecular gas content through CO emission. All these observations provide unparalleled constraints on their quenching mechanisms. Our results indicate that quiescent galaxies at z~2 (1) have short star formation timescales of a few hundred Myrs; (2) have a variety of stellar morphology from exponential disks to bulges; (3) are devoid of molecular gas; and (4) host low-luminosity active galactic nuclei which may be responsible for suppressing star formation. In addition to discussing the insights gained on quenching, I will highlight how these findings bring about new questions that can be addressed with future JWST and ALMA studies.

Cochrane

Observed and predicted high redshift galaxies, resolved across the wavelength spectrum

I will present exquisite 0.15"-resolution imaging of z~2 galaxies, mapping the H-alpha emission line (from SINFONI/VLT), UV continuum (from HST), and the far-infrared (from ALMA). These show spectacular structures, with interesting offsets between the short and long-wavelength data. The UV-derived SFR catastrophically underestimates the total, presumably due to extreme dust attenuation. This work highlights the biased view of galaxy evolution provided by UV data in the absence of long-wavelength data.
To complement this observational work, I will describe a detailed study of the spatially-resolved dust continuum emission of simulated high-redshift galaxies drawn from FIRE-2, the state-of-the-art in zoom-in cosmological hydrodynamical simulations. Using sophisticated radiative transfer techniques, I have derived predictions for the full rest-frame far-ultraviolet-to-far-infrared Spectral Energy Distributions of these simulated galaxies, as well as extremely well-resolved maps of their multi-wavelength emission. These maps show striking differences with wavelength, with the same galaxy appearing clumpy and extended in the far-ultraviolet yet compact at far-infrared wavelengths, just as in observed galaxies. The observed-frame 870um half-light radii of the FIRE-2 galaxies are ~0.5-4kpc, consistent with existing ALMA observations of high redshift galaxies. In both simulated and observed galaxies, the dust continuum emission is more compact than the cold gas, but more extended than the stellar component. The most extreme cases of compact dust emission seem to be driven by particularly compact recent star formation.

Tadaki

A sub-kiloparsec-scale view of un-lensed submillimeter galaxies

Submillimeter galaxies at z>4 are the most likely progenitors of compact quiescent galaxies at z=1-3, and eventually giant ellipticals in the local Universe. They are commonly building up their central cores through extremely compact starbursts with an effective radius of 1-2 kiloparsec. The physical processes inside these compact starburst cores are poorly understood because dissecting them requires sub-kiloparsec resolution, even higher than the Hubble Space Telescope can offer.
Our ALMA observations at 0.08-arcsec (550 parsec) resolution reveals off-center gas clumps in an un-lensed submillimeter galaxy at z=4.3 as well as a rotation-dominated disk. Exploiting the kinematic properties and the spatial distribution of molecular gas mass surface density, we find a

strong evidence that the starburst disk is gravitationally unstable, implying that the self-gravity of gas overcomes the differential rotation and the internal pressure by stellar radiation feedback. The observed molecular gas would be consumed by star formation in a timescale of 100 million years. Our results suggest that compact cores are formed through an extreme starburst event due to a gravitational instability in the central 2 kpc region. The stellar continuum emission in such a dust-obscured core is very faint at HST/WFC 1.6um band due to strong dust extinction while it is very bright at Spitzer/IRAC 3-4 um band. Therefore, submillimeter galaxies at z>4 are an ideal target for ALMA-JWST synergetic observations at sub-kiloparsec resolution, covering all aspects of stars, gas and dust in the progenitors of elliptical galaxies.

SESSION 7

Amorin (invited)

Analogos of high redshift galaxies: disentangling the complexity of the green peas

Young low-mass galaxies with extreme emission-line properties are ubiquitous at high redshift. However, a detailed characterisation of their physical properties, key for understanding cosmic reionisation and the early growth of galaxies, will be only possible with JWST and ELT observations. Rare lower-z analogues of these primeval galaxies provide us ideal laboratories to study in larger detail the complex physical mechanisms taking place in these extreme systems.
In this talk, I will review key results from these high-z analogues, with an emphasis on lessons learned from deep spectroscopic observations of green pea galaxies at z<~0.3. New recent results based on high-dispersion echelle and IFU spectroscopy of green peas will be presented. They illustrate current advantages and limitations of the chemodynamical analysis for a simultaneous study of the ionised gas kinematics, chemical enrichment and the escape of ionising photons in compact low-mass starbursts.

Jaskot

Neutral Gas and the Escape of Ionizing Radiation: Lessons from the Low-Redshift Green Peas

How galaxies reionized the universe remains an open question, but we can gain insights from the low-redshift Green Pea galaxies, one of the only known populations of Lyman continuum (LyC) emitters. Using VLA HI 21 cm observations and HST UV spectra of Green Peas, I will discuss how their neutral gas content and geometry influence LyC and Ly-alpha escape. The neutral gas in the Green Peas is distributed inhomogeneously; low neutral gas covering fractions are common among the population, but not all lines of sight are optically thin. Young, metal-poor stellar populations with high ionizing photon production appear to be a key characteristic of LyC-emitting candidates, but surprisingly, galaxy outflows are not necessary for low optical depths. I will address the implications of these results for identifying LyC emitters at high redshift with JWST and ALMA.

Bian

Evolution of Ionized Interstellar Medium from High-redshift to Low-redshift

The ionized interstellar medium (ISM) provides essential information on the star-forming environments, metal enrichment, and underlying ionizing radiation field in galaxies. It is crucial to understand how the ionized ISM evolves with Cosmic time. In this talk, I will present a sample of local galaxies that closely resemble the properties of high-redshift galaxies at high redshift. These local analogs of high-redshift galaxies provide a unique local laboratory to study high-redshift galaxies. I will discuss how to use these analogs to improve our understanding of the high-redshift metallicity empirical calibrations and physical mechanism(s) to drive the evolution of optical diagnostics lines from high redshift to low redshift.

Saintonge (invited)

The gas content of local to intermediate-redshift galaxies

TBD

Gonçalves

ALMA observations of local analogs of high-redshift star-forming galaxies

I will present the result of two observational projects using ALMA to investigate the properties of the molecular gas in low-redshift (z~0.2) ultraviolet-luminous galaxies. These objects are extremely dense, highly star-forming and very metal-poor compared to other galaxies of similar stellar mass at the same redshifts, justifying their use as analogues to distant main-sequence galaxies in an attempt to understand the interplay between gas and star formation under similar conditions in the early universe. Firstly, we have observed the most metal-poor objects in our sample, in order to determine whether metallicity plays a role in CO emissivity of the molecular regions in these galaxies. Our four non-detections, with stringent upper limits, shows that CO is severely depleted, even under turbulent conditions. We have also observed one object with high spatial resolution, comparing data from CO emission and hydrogen recombination lines down to a resolution of ~400 pc, allowing for a detailed analysis of the conversion of gas into new stars. We are able to compare star formation laws in individual clumps and the surrounding ISM, highlighting the difference between star formation efficiencies in each environment within the galaxy. Finally, the high-resolution data offers interesting insights on the growth of supermassive black holes in these galaxies: our combined multiwavelength data shows that there must be a low-mass (10^5 Msun) black hole in the center of the galaxy, while bolometric luminosity in the central region is dominated by star formation activity.

Weisz (invited)

Lessons from the Local Universe

Resolved galaxies in the local Universe are fundamentally connected to galaxies observed at all cosmic epochs. The IMF, extinction law, distance ladder, and stellar evolution are all anchored in observations of resolved stars in the nearby Universe. In this talk, I highlight new links between resolved galaxies and those in the higher redshift Universe, and discuss how future observations of resolved stars are essential for a complete and accurate census of galaxy evolution across cosmic time.

Senchyna

Local star-forming dwarf galaxies as windows on reionization-era stellar populations

The recent detections of high-ionization nebular line emission from species including CIV in a number of z>6 galaxies have highlighted substantial deficiencies in our understanding of metal poor stars. Prominent nebular CIV has never been detected in purely star-forming systems locally, and the massive star models used to model this emission in photoionization codes have not been empirically calibrated below the metallicity of the SMC (20% solar). As a result, we are presently entirely unprepared to correctly interpret nebular emission from metal-poor stars observed with JWST and ALMA in the reionization era. We present results from a multi-pronged ongoing local ultraviolet/optical observation campaign with HST/COS, Keck/ESI, and MMT designed to address this issue by locating and characterizing stellar populations capable of powering such high-ionization emission. This work has already demonstrated that strong nebular CIV can be powered by extremely metal-poor (<10% solar) massive stars, indicating that we may already have evidence of such low-metallicity populations in the reionization era. However, CIV at the equivalent widths detected at z>6 remains elusive locally, potentially in part due to the relative paucity of known nearby galaxies at these metallicities with massive stellar populations comparable to those in z>6 systems. We present a new technique to locate such nearby galaxies, and results from optical follow-up which indicate that a substantial population of highly star-forming metal-poor galaxies likely resides just below the detection limits of previous large spectroscopic surveys.

Fisher

DYNAMO: An Upclose View of Turbulent, Clumpy Galaxies

Over 2/3 of all star formation in the Universe occurs in gas-rich, super-high pressure clumpy galaxies in the epoch of redshift z~1-3. However, because these galaxies are so distant we are limited in the information available to study the properties of star formation and gas in these systems. I will present results using a sample of extremely rare, nearby galaxies (called DYNAMO) that 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. We therefore use DYNAMO galaxies as laboratories to study the processes inside galaxies in the dominate mode of star formation in the Universe. In this talk I will report on results from our programs with HST, ALMA, Keck, and NOEMA for DYNAMO galaxies that are aimed at testing 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; conversely, predictions of models in which turbulence is driven by gravity only are not consistent with our data. I will also show that feedback-regulated star formation can explain the redshift evolution of galaxy star formation efficiency. I will also present results from a recently acquired map of CO(2-1) in a clumpy galaxy with resolution less than 200 pc. With maps such as these we can begin to study these super giant star forming clumps at scales that are more comparable to local surveys. I will show results for the star formation efficiency of clumps, the boundedness of clumps of molecular gas, and discuss links between star formation efficiency and formation of clumps of stellar mass. The details of clumpy systems are a direct constraint of the results of simulations, especially on the nature of feedback in the high density environments of star formation that dominate the early Universe.

SESSION 8

Bacon (invited)

Galaxies at high z: the MUSE revolution

Spectroscopic observations of galaxies at high redshift has recently been revolutionised by the Multi Unit Spectroscopic Explorer (MUSE) instrument in operation at the VLT since 2014.
Thanks to its unrivalled capabilities, MUSE has been able to increase by an order of magnitude the number of spectroscopic redshifts in these fields. The most spectacular increase is at high redshift (z>3), where MUSE was able to detect thousands of Lyman-alpha emitters. In the deepest exposures, MUSE is even able to goes beyond the limiting magnitude of the deepest HST exposures.
These observations have led to a breakthrough in our understanding of the high redshift universe: e.g. the discovery of Lyman-alpha emission from the circumgalactic medium around individual galaxies, the role and property of low mass galaxies.
In this talk I will present the latest results obtained with the MUSE observations of the Hubble deep and ultra-deep fields.

Boogaard

Nature and physical properties of gas-mass selected galaxies using integral field spectroscopy

Mapping the molecular gas content of the universe is key to our understanding of the build-up of galaxies over cosmic time. Spectral line scans in deep fields, such as the Hubble Ultra Deep Field (HUDF), provide a unique view on the cold gas content out to high redshift. By conducting `spectroscopy-of-everything', these flux-limited observations are sensitive to the molecular gas in galaxies without preselection, revealing the cold gas content of galaxies that would not be selected in traditional studies.
In order to capitalise on the molecular gas observations, it is key to know about the physical conditions of the galaxies detected in molecular gas, such as their ISM conditions. Fortunately, deep surveys with integral-field spectrographs are providing an unprecedented view of the galaxy population, providing redshifts and measurements of restframe optical/UV lines for thousands of galaxies.
In this talk, we present the results from synergising the ALMA Spectroscopic Survey of the HUDF (ASPECS), with deep integral field spectroscopy from the MUSE HUDF survey and multi-wavelenth data. We discuss the nature of the galaxies detected in molecular gas without preselection and their physical properties, such as star-formation rate, metallicity and AGN activity. We show how the the combination of ALMA and MUSE integral field spectroscopy can constrain the physical properties in galaxies located around the main sequence during the peak of galaxy formation.

Maseda

Ultra-faint Lyman Alpha Emitters with MUSE

Using an ultra-deep blind survey with the MUSE integral field spectrograph on the ESO Very Large Telescope, we obtain spectroscopic redshifts to a depth never explored before: galaxies with observed magnitudes $m > 30$-32. Specifically, we detect objects via Lyman-alpha emission at $2.9 < z < 6.7$ without individual continuum counterparts in areas covered by the deepest optical/near-infrared imaging taken by the Hubble Space Telescope, the Hubble Ultra Deep Field. In total, we find more than 100 such objects in 9 square arcminutes at these redshifts, also including a number of sources that are visible only in the HST band that contains Lyman-alpha. Detailed HST and IRAC stacking analyses confirm the Lyman-alpha emission as well as the 1216 Angstrom breaks, faint UV continua ($M_{UV} \sim -15$), and optical emission lines: these objects are the faintest spectroscopically-confirmed galaxies at high-z. The blue UV continuum slopes and measurements/limits on the equivalent widths of Lyman-alpha, which in some cases exceeds 300 Angstroms, are consistent with ages < 10 Myr, metallicities < 5% solar, and stellar masses < 10^7 solar masses. Spectral stacks from MUSE provide limits on the strength of metal emission lines such as C IV, He II, and C III] which shed light on the source of the ionizing photons in these systems. The nature of these types of objects is intriguing as they could be the faint star-forming sources of Reionization and could represent the initial (strong) phase of stellar mass growth in galaxies.

Alves de Oliveira

The role of the JWST near-infrared spectrograph NIRSpec in understanding the assembly and evolution of galaxies

The near-infrared spectrograph NIRSpec is one of four instruments aboard the James Webb Space Telescope (JWST). It offers seven dispersers covering the wavelength range from 0.6 to 5.3 micron with resolutions from $R\sim100$ to $R\sim2700$. Using an array of micro-shutters for target selection, the multi-object spectroscopy mode of NIRSpec will be capable of obtaining spectra from a few tens to more than 200 objects simultaneously. It also features an integral field unit with a 3 by 3 arcseconds field of view, and various slits for high contrast spectroscopy of individual objects.
We will provide an overview of the capabilities and performances of these three observing modes highlighting how NIRSpec will contribute to the quest to further understand the assembly and evolution of galaxies from the end of re-ionisation epoch to the present day.

Rieke

JWST Advanced Deep Extragalactic Survey: NIRCam Imaging to $z>10$

The JWST Advanced Deep Extragalactic Survey (JADES) is a joint program of the JWST/NIRCam and NIRSpec Guaranteed Time Observations (GTO) teams involving 950 hours of observation. This presentation will cover the imaging portion of the program which covers nearly 200 square arc minutes divided between two well-studied fields with excellent supporting data (e.g. from HST-CANDELS): GOODS-North and South, including the Ultra Deep Field. NIRCam imaging will enable the study of galaxy evolution to $z\sim10$ and higher using multi-color NIRCam imaging with 9 filters covering 0.9 to 5 microns. Such data will provide photometric redshifts and a wealth of data for constructing luminosity and mass functions. A key component of the program is rapid turn around of imaging into NIRSpec target lists, and the development of a mock catalog and simulated imaging to test this process will also be described.

Bunker

Spectroscopy with the JWST Advanced Deep Extragalactic Survey (JADES) - the NIRSpec/NIRCAM GTO galaxy evolution project

I will present an overview of the spectroscopy in the JWST Advanced Deep Extragalactic Survey (JADES), a joint program of the JWST/NIRCam and NIRSpec Guaranteed Time Observations (GTO) teams involving 950 hours of observation. We will target two well-studied fields with excellent supporting data (e.g. from HST-CANDELS): GOODS-North and South, including the Ultra Deep Field. The science goal of JADES is to chart galaxy evolution at z>2, and potentially out to z>10, using the rest-frame optical and near-IR though observations from 1-5microns. NIRSpec spectroscopy (with spectral resolving powers of 100, 1000 & 2700) will measure secure spectroscopic redshifts of the photometrically-selected population, as well as stellar continuum slopes in the UV rest-frame, and hence study the role of dust, stellar population age, and other effects. Measuring emission lines can constrain the dust attenuation, star formation rates, metallicity, chemical abundances, ionization and excitation mechanism in high redshift galaxies. Coupling NIRCam and NIRSpec observations will determine stellar populations (age, star formation histories, abundances) of galaxies and provide the information to correct their broad-band spectral energy distribution for likely line contamination. Potentially we can search for signatures of Population III stars such as HeII. We can address the contribution of star-forming galaxies at z>7 to reionization by determining the faint end slope of the luminosity function and investigating the escape fraction of ionizing photons by comparing the UV stellar continuum with the Balmer-line fluxes.

Kassin

Toward a New Understanding of Disk Galaxy Formation

One of the most important open issues in astronomy is the assembly of galactic disks. Over the last decade this has been addressed with large surveys of the internal kinematics of galaxies spanning the last 10 billion years of the universe. I will discuss recent results from the field that show the kinematic assembly of disk galaxies since a redshift of 2.5, including recent deep 10-30 hour observations by my group with the DEIMOS spectrograph on Keck. These results strongly challenge traditional analytic models of galaxy formation and provide an important benchmark for simulations.
Furthermore, I will discuss our plans for extending measurements to higher redshifts with future instruments such as the JWST\'s NIRSpec IFU and the E-ELT\'s MOSAIC and HARMONI IFUs. From mock JWST and E-ELT observations of simulated galaxies, we are learning that interpreting these observations of galaxies in the early universe, when merging is frequent, is not necessarily straightforward.

Mutch

Connecting observations of the first galaxies and the Epoch of Reionisation

Dwarf galaxies are thought to be dominant contributors of ionizing photons during the Epoch of Reionisation (EoR). Our knowledge of the statistics of these high redshift galaxies is constantly improving and will take yet another important step forward with the launch of JWST. At the same time, the upper limits on the EoR 21cm power spectrum are continually falling, with a firm measurement from SKA-low being a certainty in coming years. In order to maximise what we can learn from these two complimentary observational datasets, we need to be able to model them together, self-consistently. In this talk, I will present insights into the connection between galaxy formation and the EoR gained from the DRAGONS suite of semi-analytic and hydrodynamic galaxy formation simulations. Using these we find that the steep faint end slope of the high-redshift galaxy UV luminosity function extends well beyond current observational limits, indicating that only ~50% of the ionising photons available for reionisation have been observed at z<7. I will also discuss the relative contribution of quasars to reionisation and present constraints on ionising escape fraction models.

Casey (invited)

The Brightest Galaxies in the Dark Ages: Galaxies' Dust Continuum Emission out to the Reionization Era

Though half of cosmic starlight is absorbed by dust and reradiated at long wavelengths (3μm–3mm), constraints on the infrared through millimeter galaxy luminosity function (the 'IRLF') are poor in comparison to the rest-frame ultraviolet and optical galaxy luminosity function, particularly at z => 2.5. Here we present a backward evolution model for interpreting number counts, redshift distributions, and cross-band flux density correlations in the infrared and submillimeter sky, from 70μm–2 mm, using a model for the IRLF out to the epoch of reionization. Mock submillimeter maps are generated by injecting sources according to the prescribed IRLF and flux densities drawn from model spectral energy distributions that mirror the distribution of SEDs observed in 0 < z < 5 dusty star-forming galaxies (DSFGs). We explore two extreme hypothetical case-studies: a dust-poor early Universe model, where DSFGs contribute negligibly (<10%) to the integrated star-formation rate density at z > 4, and an alternate dust-rich early Universe model, where DSFGs dominate >90% of z > 4 star-formation. We find that current submm/mm datasets do not clearly rule out either of these extreme models. We suggest that future surveys at 2 mm -- both from ALMA and single-dish facilities -- will be crucial to measuring the IRLF beyond z > 4.