Quasars and Galaxies on the Edge of Cosmic Reionisation

Preparing to Interpret Data from the New Generation of Facilities

Quasars at High Redshift

10:40 - 11:00 Roberto Maiolino (University of Cambridge)

Review: The First Quasars

In the past few years we have seen tremendous progress in the discovery and characterisation of quasars in the primeval Universe. These impressive systems offer the unique opportunity to explore the early phases of the formation of massive galaxies and supermassive black holes. Although observations with cutting edge facilities and advanced numerical simulations have shed light on the nature of these fascinating objects, many of their properties remain puzzling. I will discuss what we understand and, even more interestingly, what we do not understand of these enigmatic systems, primarily through an overview of recent observational results, but also discussing some of the recent models and simulations. I will then discuss how forthcoming observing facilities will allow us to comprehend some of the most puzzling aspects still embedding this class of objects.

11:00 - 11:12 Marcel Neeleman (MPIA)

ALMA's High Resolution View of $z > 6$ Quasar Host Galaxies

Imaging and characterizing the stellar component of the host galaxies of $z \sim 6$ quasars is one of the key science drivers of JWST. ALMA, however, has been routinely detecting the emission of the interstellar medium (ISM) of $z > 6$ quasar host galaxies using the fine structure line of ionized carbon ([CII]) for almost a decade. The unique capabilities of ALMA allow us to probe the ISM of $z > 6$ quasar host galaxies at spatial resolutions comparable (or in some cases much better) to those that will be obtained with JWST.

In this talk, I will present the results from a series of three papers that study the [CII] and dust continuum emission from a sample of 27 $z > 6$ quasar host galaxies at a spatial resolution < 0.25 arcsec. This is the largest sample of resolved observations of the ISM in $z > 6$ quasar host galaxies. Key results from these studies include: 1) the quasar properties appear unrelated to either the dust continuum or [CII] emission line, 2) the majority of the quasar host galaxies do not show any evidence for high velocity [CII] outflows, and 3) the extent of the [CII] and dust continuum emission is consistent with numerical simulations. Finally, we measure the kinematics of the [CII] emission line revealing that roughly a third of the $z > 6$ quasar host galaxies have velocity fields consistent with a rotating disk galaxy. Modeling of the kinematics yield an estimate of the dynamical mass that is smaller than expected based on the mass of the black hole and the locally derived correlation between these two quantities.

These studies have revealed the spatial extent and complexity of the interstellar medium of $z > 6$ quasar host galaxies, and provide a unique resolution-matched sample for comparison with future JWST observations of the stellar component in these galaxies.

11:12 - 11:24 Daniel Whalen (ICG, Portsmouth)

The First Quasars in the Universe

Over 300 quasars have now been found at $z > 6$, less than a Gyr after the Big Bang (with seven at $z > 7$). How such massive BHs formed by such early epochs poses significant challenges to current paradigms of early structure formation. I will review current thought on the origins of primordial quasars and present new radiation hydrodynamical simulations demonstrating how a 2 billion solar mass BH can form by $z \sim 7$. I will also present synthetic observables for the first quasars in the NIR and radio for each stage of their evolution: birth as a supermassive primordial star, collapse to a DCBH, and subsequent growth to 10^9 solar mass BH in cold accretion flows. Our calculations show that Euclid, JWST and the SKA will inaugurate the era of $z \sim 5$–15 quasar astronomy in the coming decade.

11:24 - 11:36 Roberto Gilli (INAF - OAS Bologna)

Web of the giant: spectroscopic confirmation of a large scale structure around a supermassive black hole at cosmic dawn

I will report on the discovery of a galaxy overdensity around the luminous quasar SDSS J$1030+0524$ at $z = 6.31$. The structure is populated by at least six members, identified through dedicated spectroscopic campaigns at the Keck, VLT and LBT, with redshifts in the range $6.219 - 6.355$. Assuming negligible peculiar velocities, this range corresponds to radial separations of ~ 5 physical Mpc from the QSO, that are comparable to the observed projected separations. The result is significant at more than 3.5sigma, and the overdensity level is at least 1.5-2 within the large volume probed (~ 780 physical Mpc^3). This is the first spectroscopic confirmation of a galaxy overdensity around a supermassive black hole in the first billion years of the Universe. Our finding lends support to the idea that the most distant and massive black holes form and grow within massive ($> 1e12$ Msun) dark matter halos in large scale structures, and that the absence of earlier detections of such systems was likely due to observational limitations. Prospects for future JWST observations are discussed.

11:36 - 11:48 Rebecca Bowler (University of Oxford)

Determining the faint-end of the rest-frame UV AGN luminosity function at high-redshift

At high-redshifts, the populations of quasars and galaxies have previously been treated separately, due to the disparate parameter space searched to-date (e.g. all sky vs. ultra-deep fields). Recently the creation of degree-scale extragalactic surveys has led to the first samples of 'intermediate' luminosity sources. In this study we investigate the properties of these intermediate sources at $z \sim 4$, using high-resolution imaging from Hubble and archival spectroscopy. These data show a clear change in the morphology and spectral features around an absolute magnitude of $Muv = -23.2$, suggestive of a rapid transition between AGN and star-formation (SF)-dominated rest-frame UV light. We use our data to separate the rest-frame UV luminosity function at intermediate luminosity into AGN/SF components for the first time. Our results suggest that the AGN LF has a steeper faint-end slope than recent studies have found (alpha= $-1.83pm0.11$). Using an empirical model we demonstrate that this is due to incompleteness in previous AGN samples that impose a point-source criterion. We find that the increasing impact of host galaxy light must be taken into account to adequately understand the faint AGN population, in particular when considering the role of AGN in the Reionization of the Universe.

Galaxies at High Redshift

11:50 - 12:10: Steve Wilkins (University of Sussex)

Review: Galaxies across the First Light and Reionisation Epoch

The First Light And Reionisation Epoch (FLARE), roughly the first billion years, is a critical period in the Universe's history. The FLARE encompasses: the formation of the formation of the first stars; the transition from metal-free (population III) to metal enriched (Population II) star formation; early enrichment of the ISM including the first production of dust; the formation of the first super-massive black holes and AGN; and reionisation of the Universe's neutral hydrogen. While Hubble and other telescopes have provided our first glimpse of the FLARE the upcoming facilities such as Webb and Euclid will allow us to explore the early Universe in much more depth.

In this overview talk, I will provide some of the context for our study of this period of the Universe's history, including outlining some of the key outstanding question. I will then describe what we can learn about high-redshift galaxy formation from observations using both current and future observatories. Finally, I will briefly describe some of the techniques used to model galaxies.

13:30 - 13:42 Mauro Stefanon (University of Leiden)

Star-formation efficiency in the first Gyr of cosmic time

In the last decade, the increased sensitivity of HST/WFC3 combined with Spitzer/IRAC coverage have enabled the identification of more than 2000 galaxies at $z > 6$. 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 $z \sim 8$, 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)$>\sim 1000$AA), 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. In the second part of the talk, we will present our most recent results on the evolution of the stellar mass function of galaxies in the first Gyr of cosmic time and of the star-formation efficiency to $z \sim 8-10$. Our analysis leverages the totality of IRAC observations acquired across 12 years of Spitzer/IRAC observations over the GOODS fields which we publicly release as part of the GOODS Re-ionization Era wide Area Treasury from Spitzer (GREATS) program, the deepest NIR dataset at $3-5$um before JWST.

13:42 - 13:54 Rachana Bhatawdekar (European Space Agency)

Studying the faint galaxies in the epoch of reionisation era combining HST and the power of gravitational lensing

The epoch of reionisation when the Universe transformed from a neutral state to an ionised state in an important phase change in the history of our Universe. But what were the first luminous sources responsible for this phase change and when exactly did they form? These are some of the major unanswered questions in extragalactic astronomy. The James Webb Space Telescope (JWST) will be launched in 2021 and will search for the First Light objects in the redshift range of $z = 10-15$. Observing these galaxies will be routine with JWST, however, until then, our best chance to study these systems is through deep observations of lensing clusters with the Hubble Space Telescope (HST) by using them as 'Cosmic Telescopes'. Therefore, to extend its reach even farther beyond its technical capabilities before JWST is launched, the HST observed six massive clusters of galaxies as gravitational lenses to find the faintest and earliest galaxies in the Universe, $\sim$10-100 times fainter than any previously studied, as a part of the Hubble Frontier Fields (HFF) program. In this talk, I will present how we detect and examine the objects behind HFFs lensing clusters. We have developed a novel method to subtract the massive foreground galaxies from these clusters, allowing for a deeper and cleaner detection of the faintest systems. With photometry from HST, Spitzer and K-band imaging, I will present new measurements of the evolution of the galaxy stellar mass functions, UV luminosity functions, stellar mass density, UV luminosity density, and UV spectral slopes for galaxies from $z = 6-9$ in the Hubble Frontier Fields. I will further discuss how these results reveal new information on the faint-end of the mass function from the faintest galaxies at high-z, as well as their UV spectral slopes, unveiling the potential science that can be done with JWST.

13:54 - 14:06 Viola Gelli (Universita degli Studi di Firenze)

High-z Lyman Break Galaxies with JWST: parallel observations of dwarf satellites

Dwarf galaxies are the most common type of galaxies in the Universe at all epochs and they play a fundamental role in cosmic history, being responsible for the build up of massive galaxies and possibly driving the reionization and metal enrichment processes. High-redshift observations of such sources are not available yet, but we demonstrate that the James Webb Space Telescope (JWST), while targeting massive Lyman Break Galaxies (LBGs), will catch for the first time the light of the faint satellite dwarf galaxies orbiting around them.

We use state-of-art cosmological simulations of a typical LBG at $z = 6$ to uncover the properties of satellite galaxies and make predictions for the upcoming JWST observations. These dwarf galaxies cover a wide range of stellar masses (log(M/Msun)$\approx 7 - 9$). We find that, even in such extremely dense environments, internal supernovae feedback is the key mechanism regulating their evolution, capable of completely quenching dwarf galaxies. Only the frequent merger events characterising these biased regions can effectively prolong the star-formation in the most massive satellites.

Modelling the galaxies' stellar emission we reconstruct their spectral energy distributions: these reveal how with the JWST/NIRCam instrument, through colour-magnitude diagrams, it will be possible to infer properties such as the galaxies' stellar masses and ages. The instrument's high resolution will allow us to spatially resolve these small systems from the nearby host. Thanks to JWST's high sensitivities we will detect, for the very first time, faint satellite dwarf galaxies of high-z LBGs in less than 5 hours.

14:06 - 14:18 Michele Ginolfi (ESO, Garching)

Galactic feedback, gas stripping, and circumgalactic metal-enrichment in the early Universe

Galaxies evolve under the influence of gas exchanges with their surrounding gaseous halos, the so-called circumgalactic medium (CGM), extending over tens of kpc. Thus, a solid characterisation of both galactic gas flows and chemical composition of the CGM is crucial to understand galaxy evolution, especially in the first few Gyrs of cosmic time, when galaxies rapidly assembled their masses and reached their chemical maturity. I will present new studies on galactic outflows and CGM metal enrichment in the early Universe, exploiting recent data from the ALMA large program ALPINE, that observed [CII] and dust in more than hundred distant star-forming galaxies up to $z \sim 6$. We discover signatures of star-formation-driven outflows studying both the high-velocity tails of the stacked [CII] profiles and the blueshifts of metal absorption lines in the UV spectra. We find that despite their moderately low velocities and mass-loading factors, outflows can efficiently eject metals in the CGM and contribute to its chemical evolution, as suggested by the detection of large [CII]-halos extended on ~ 20 kpc around massive galaxies. Also, we find evidence that in dense environments the CGM metal pollution is mostly driven by tidal stripping, that can remove a significant fraction of processed gas from the outer regions of galaxies and mix it with their pristine surroundings. Altogether, our findings suggest that outflows, dynamical interactions and gas exchanges with the CGM are at work in regulating the evolution of galaxies and their environment already at very early cosmic epochs.

The Future

14:20 - 14:40: Emma Curtis Lake (University of Cambridge)

Review: The Future: JWST and other upcoming facilities

I will outline how JWST will transform our understanding of the formation and evolution of galaxies and Quasars in the early Universe in the very near future. However powerful JWST will be, it is by no means the end of the story. There are several upcoming instruments and observatories that are necessary to provide a complete picture of this fundamental epoch of our Universe. I will summarise the timeline and complementarity of these forthcoming facilities.

14:40 - 14:52 Marusa Bradac (UC Davis)

The Final Frontier: Galaxies at the Epoch of Reionization with JWST

When did galaxies start forming stars? What is the role of distant galaxies in galaxy formation models and the epoch of reionization? What are the conditions in typical low-mass, star-forming galaxies at $z \sim 6$ and above? Recent observations with HST and Spitzer indicate several critical puzzles in studies that address these questions. Chief among these, galaxies might have started forming stars earlier than previously thought (< 400Myr after the Big Bang) and their star formation history differs from what is predicted from simulations. HST and Spitzer play a unique role in advancing our understanding of these puzzles. Deep observations probe rest-frame UV and optical properties of these galaxies, and its remarkable sensitivity enables us to observe these sources in detail at $z > 7$. I will present results the latest results from our deep HST and Spitzer surveys targeting cosmic telescopes (Hubble Frontier Fields and RELICS) showing successful measurements of the properties of stellar populations and identifying new puzzles facing future surveys at $z \sim 7$ and beyond. These observations were key in developing our large GTO and ERS JWST programs that will observe reionization galaxies behind six extraordinary cosmic telescopes. I will present the design of the surveys as well as the products we plan to provide to the broader community in advance of JWST Cycle 2.

14:52 - 15:04 David Sobral (Lancaster University)

Resolving the most extreme hosts of ionized bubbles at the end of cosmic reionization with HST, MUSE, ALMA and soon JWST

Spectroscopically confirmed luminous Lyman-alpha (Lya) emitters at $z > 6.5$ reside in ionised bubbles that allow their Lya photons to escape the resonance frequency of intergalactic neutral gas. However, is it the ”escape”, or the ”production” of Lya photons that is special in these extreme line-emitting sources compared to the numerous galaxies for which Lya is undetected? Are they all multiple mergers? What are their metallicities and stellar populations? Do they contain AGN? I will present the latest results that allow us to resolve luminous Lyman-alpha emitters within the epoch of re-ionisation with HST (rest-frame UV), MUSE (Lyman-alpha) and ALMA ([CII] and dust continuum). These sources show a wide diversity of [CII] clumps and luminosities, different spectroscopically confirmed components and likely very low metallicities. All these sources are already providing us a glimpse of what JWST may be able to unveil, along with showing us how important IFU observations of sources within the epoch of re-ionisation will be.

15:04 - 15:16 Daniel Mortlock (Imperial College London & Stockholm University)

High-redshift quasars with Euclid

Euclid's combination of large sky area and near-infrared and optical imaging capabilities means that it will revolutionise our knowledge of high-redshift quasars at z$>$ 7, including the first discoveries at $z \sim 8$. I will summarise the predicted yield from detailed catalogue level simulations (described in full by Euclid Collaboration, Barnett, R.B., et al., 2019, A&A, 631, A85, arXiv:1908.04310), the likely requirements for follow-up observations (mainly spectroscopy) to both confirm candidates and perform science exploitation, and the likely science highlights of the final high-redshift quasar sample.

15:16 - 15:28 Anna Schauer (UT Austin)

The Ultimately Large Telescope

The launch of the James Webb Space Telescope will open up a new window for observations at the highest redshifts, reaching out to $z \approx 15$. However, even with this new facility, the first stars will remain out of reach, as they are born in small minihalos with luminosities too faint to be detected even by the longest exposure times. We have investigated the basic properties of the Ultimately Large Telescope, a facility that can detect Population III star formation regions at high redshift. Observations will take place in the near-infrared and therefore a Moon-based facility is proposed. An instrument needs to reach magnitudes as faint as 39 mag$_{AB}$, corresponding to a primary mirror size of about 100 m in diameter. Assuming JWST NIRCam filters, we estimate that Population III sources will have unique signatures in a color-color space and can be identified unambiguously.