



ACCADEMIA NAZIONALE DEI LINCEI

INTERNATIONAL CONFERENCE

EARLY GALAXIES AND INFANT BLACK HOLES: FORMATION AND GROWTH AT COSMIC DAWN

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ABSTRACTS

The First Chapters of Galaxy Build-up Revealed by JWST (& Euclid and Roman)

Pascal OESCH (University of Geneva & DAWN Copenhagen)

The first deep images with the James Webb Space Telescope (JWST) have transformed our view of the Universe. From day one, JWST produced one surprise after another: from unexpectedly luminous galaxies at $z > 10$, to an abundant new class of obscured black holes, to massive quiescent galaxies when the Universe was only 1–2 Gyr old. JWST has extended our cosmic horizon into uncharted territory, with galaxies spectroscopically confirmed to $z \sim 14$ and candidates out to $z \sim 16+$, only ~ 250 – 300 Myr after the Big Bang. Deep grating spectroscopy now goes beyond redshifts, revealing exotic chemical abundance patterns such as strong nitrogen enhancement and possible signatures of very massive stars, which point to extreme modes of star formation in dense clusters, perhaps akin to the formation of globular clusters. However, JWST's deep fields cover less than one square degree, and thus miss the rarest and most luminous sources, which hold key constraints on the efficiency of early galaxy growth. Wide-area near-infrared surveys with Euclid and Roman will change this, covering many square degrees and finding large samples of bright galaxies in the first billion years. In this talk, I will review what JWST has taught us about early galaxy build-up over the past ~ 4 years, and discuss how the combination of JWST depth with the area of Euclid and Roman will open the next chapter in our understanding of cosmic dawn.

Uncovering the First Stars through Living Relics and Direct Detection

Stefania SALVADORI (University of Florence / Arcetri)

The nature of the first stars, born from pristine, primordial gas (PopIII), and of the earliest PopIII galaxies that hosted them remains a mystery. So far, no metal-free stars have been detected among ancient stellar populations in the Local Group, supporting the idea that PopIII stars were likely more massive than stars forming under present-day conditions. Massive PopIII stars are predicted to have hard spectra, producing characteristic HeII recombination lines in their host galaxies. They are also expected to end their lives rapidly as supernovae (SNe), enriching their surroundings with newly forged metals. Thus, within self-enriched PopIII galaxies, normal, low-mass stars could subsequently form and survive to the present day as living relics of the earliest cosmic epochs.

In this talk, I will show how the combination of spectroscopic observations of nearby stellar relics and direct JWST observations of distant pristine galaxies provides a unique opportunity to advance our understanding of the properties of the first cosmic sources. By bringing together the latest observational and theoretical results from both Near- and Far-field cosmology, I will discuss the emerging picture of the nature of PopIII stars and galaxies, while highlighting the key questions that remain open.

Charting the emergence of the first galaxies with JWST

Prof James DUNLOP (University of Edinburgh)

The James Webb Space Telescope (JWST) is transforming our view of galaxy formation and evolution in the young Universe. I will provide an overview of the latest results from the PRIMER survey, the largest JWST Cycle-1 “Galaxies” programme which, in combination with other public JWST imaging, is now enabling us to chart the emergence of the galaxy population back to within ~ 300 million years of the Big Bang. Specifically, I will present and discuss the first robust determination of the evolving UV galaxy luminosity function extending back to redshifts $z \sim 13$, new measurements of the galaxy stellar mass function reaching out to $z \sim 9$, and the latest searches for galaxies at $z > 15$. I will then interpret these results in the context of our current understanding of the evolving dark matter halo mass function and the efficiency with which galaxies are able to convert their baryons into stars.

The Beautiful Confusion. Super-Early Galaxies seen by the James Webb Space Telescope

Andrea FERRARA (SNS Pisa)

The James Webb Space Telescope is revealing the Universe as it appeared only a few hundred million years after the Big Bang. Its unprecedented sensitivity has uncovered surprisingly bright, blue and numerous young galaxies, challenging our understanding of how the first cosmic structures formed. In this talk, I will present the most exciting discoveries from JWST, explain what they tell us about the birth of galaxies and stars, and discuss the new questions that these remarkable observations have raised about the early Universe.

Chemical enrichment of high- z galaxies: latest results from JWST

Mirko CURTI (INAF OAS)

In just a few years, JWST has completely revolutionized the study of the chemical evolution of galaxies in the early Universe. Deep spectroscopy have delivered electron-temperature (T_e)-based abundances for hundreds of galaxies at $z > 1$ and out to $z > 10$, large statistical samples have expanded the investigation of metallicity scaling relations to uncharted regions of the parameter space, and combined rest-frame UV-to-optical spectroscopy has given access to multiple elemental abundances beyond oxygen, providing complementary information on the star-formation history of galaxies.

In this talk, I will summarize both recent progress and outstanding questions in the field.

I will first discuss new metallicity diagnostics calibrated directly on high-redshift spectra and the systematics that still impact their accuracy, from sample selection biases to the presence of high gas density clumps that can mimic extremely low metallicities.

I will then review recent constraints on galaxy evolution models set by the study of the mass-metallicity and fundamental metallicity relations out to $z \sim 10$ --and down to the low-mass regime-- in the context of bursty star formation and metal-loaded outflows.

Finally, I will focus on elemental abundance patterns, ranging from the population of N/O-enhanced galaxies at low metallicity, to the diversity of C/O measurements, to the level of α -enhancement now also probed in absorption at $z > 7$. These point to short enrichment timescales and possibly to extreme stellar populations, including Wolf-Rayet stars, Very Massive Stars, and potential contributions from Pop III stars.

The Dusty Metal-Poor Phase of Early Galaxy Growth

Karina CAPUTI (Kapteyn Institute, Groningen)

Low-mass galaxies (with stellar masses $< 10^9 M_{\odot}$) are fundamental to understand the first steps of galaxy growth. For many years, the study of low-mass sources in the local Universe has given us a glimpse of the conditions that would likely have applied to their analogues at early cosmic times. Now, thanks to the superb sensitivity of JWST, we can directly study in detail the properties of low-mass galaxies up to very high redshifts. In this talk I will present the results of our JWST spectroscopic study of a large sample of low-mass galaxies present in the Universe between the end of the Epoch of Reionisation and the following billion years, which is a critical period for early galaxy growth. I will especially discuss the effect of burstiness on the galaxy spectral properties. I will then focus in particular on the subset of galaxies that are off the dust-attenuation versus metallicity relation, such that they are significantly dusty while still relatively metal-poor, and discuss their nature. I will finally explore connections between this out-of-equilibrium phase and the triggering of nuclear activity.

The possible connection between populations in Globular Cluster and the N—loud high—redshift galaxies

Francesca D'ANTONA (INAF- Osservatorio Astronomico di Roma)

In some high-redshift galaxies, a large ratio N/O is detected in the gas close to their central supermassive black hole (BH), in the range of the $\log(\text{N}/\text{O})$ values found in the “multiple populations” of Globular Clusters (GC). Compact and massive GCs (the Nuclear Star Clusters, NSC) are also a privileged site to form and grow the seed BHs which eventually will reach the billion solar masses of quasars at redshift 6-7, so it appears probable that the formation of multiple populations and the growth by accretion of the central BH are concomitant aspects of a single scenario. In this talk I will deal with formation and evolution of NSCs in the framework of the “AGB model”, which ascribes the formation of multiple populations to the role of the wind ejecta of massive Asymptotic Giant Branch Stars. I point out the qualitative difference between some other popular models for multiple populations and the AGB model, stressing the different timescale on which they operate and comparing the chemical patterns predictions. An interesting point in the context of highz galaxies is the difficulty to reproduce the atypically extreme N/O abundance in GS_3073 with structures different from the AGB gas composition.

The extension of the AGB model to the case of NSC is favored by the recent large spectroscopic and photometric datasets achieved for the possible NSC remnant nucleus wCentauri. I show how new models developed and proposed for wCentauri give hints on the chemistry of the N/O rich AGNs in the young Universe, on the modulation of gas accretion on the central BH, and possibly on the evolutionary stage of Little Red Dots.

A possible explanation for the high N/O ratios in high redshift galaxies

Francesca MATTEUCCI (University of Trieste and INAF)

The supersolar N/O ratios observed in high-redshift galaxies by JWST are not easy to explain within the framework of chemical evolution models. In this talk, I will first discuss the stellar origin of N, which can be produced either as a secondary or a primary element. Then, I will present some models for intense starbursts coupled with very efficient galactic winds in galaxies of 10^9 - 10^{10} Msun. The galactic winds are assumed to be differential, with elements produced in core-collapse supernovae being preferentially lost from the galaxies relative to those elements mainly produced in low- and intermediate-mass stars dying as white dwarfs. These models can reproduce the high N/O ratio of several galaxies, including GS_3073, with $\text{N}/\text{O} = +0.42$ dex. It is concluded that a possible explanation for the anomalous N/O ratios in high-redshift galaxies is the combination of primary N production, intense bursts of star formation, and powerful differential galactic winds that carry out more O than N. Finally, I will show some predictions about the evolution of cosmic metallicity within the framework of different galaxy formation scenarios.

The Quasi-star Channel of Supermassive Black Hole Formation

Mitchell BEGELMAN (University of Colorado Boulder)

An increasing body of evidence indicates that the seeds of supermassive black holes had to form very early and grow very rapidly. An intriguing mechanism for accomplishing this is via the core collapse of supermassive stars, which leaves behind an intermediate-mass black hole embedded in a much more massive envelope from which it accretes at a hyper-Eddington rate. The properties of such hypothetical objects, called quasi-stars, are well-constrained theoretically. In their latter stages of evolution, they are predicted to resemble the "Little Red Dots" discovered by JWST. If LRDs are indeed late-stage quasi-stars, their short predicted lifetimes suggest that the quasi-star channel is an important mode of supermassive black hole formation and early growth.

The birth and early growth of black hole seeds in the first galaxies

Raffaella SCHNEIDER (Sapienza Università di Roma)

JWST observations are revealing a surprisingly abundant population of accreting black holes in the early Universe, including systems with exceptionally high black hole-to-stellar mass ratios. These discoveries raise fundamental questions about how massive black hole seeds form and grow within the first galaxies. In this talk, I will discuss recent theoretical developments that broaden the conditions under which massive seeds can emerge, highlighting the roles of gas fragmentation, metallicity, and stellar radiative feedback. I will then explore how gas inflows,

galaxy mergers, and black hole feedback regulate subsequent accretion, including the possibility of rapid super-Eddington growth. Finally, I will discuss the implications of these processes for early black hole populations and their gravitational-wave signatures. Together, these results suggest that massive seed formation and rapid accretion are complementary pathways, both shaped by the evolving environments of the first galaxies.

Insights into gas-obscured black holes with Little Red Dots

Xihan JI (University of Cambridge)

Recent years of JWST observations have revealed a large population of compact sources with V-shaped SEDs, dubbed “Little Red Dots” (LRDs). The strong broad Balmer lines with overlaid absorption and ubiquitous V-shaped SEDs of LRDs suggest the presence of gas-enshrouded black holes. Despite all the peculiar properties, LRDs possibly represent a common phenomenon or evolutionary phase given their high number densities in the early Universe. Still, the nature of LRDs remains elusive. In this talk, I will show how the recent observations, especially in the rest-frame UV of high-redshift LRDs, deepen our understanding of the gaseous environments of LRDs. From the low-redshift side, with wide-area ground-based surveys, studies of local LRDs become another frontier. The complex absorption and weak [FeII]/FeII emission are detected with unprecedented details in local LRDs thanks to their proximity, which reveal stratified gas structures in these systems. I will discuss recent results on local LRDs and how they provide key insights into the energetics and geometry of the overall population.

Observations of Little Red Dots

Jorjyt MATTHEE (Institute of Science and Technology Austria, ISTA)

JWST has been revolutionizing the study of galaxies in the early Universe and the formation of supermassive black holes within them. In my talk I will focus on latest results on the demographics of Little Red Dots across cosmic time and on the origin of spectral diversity within the samples. I will end with discussing what I consider to be the key open questions, namely the powering source of LRDs and their formation scenarios.

Insights into reionization sources from the IGM thermal history

Laura KEATING (University of Edinburgh)

In this talk, I will discuss what is known about the thermal history of intergalactic gas across the first billion years of the Universe. This is an especially interesting time in the history of the Universe, as it coincides with the formation of the first stars, black holes and galaxies, which are thought to be responsible for heating the Universe through the emission of hard UV photons. I will describe the current state of the field from the point of view of observations and theory, highlighting what is known about the temperature of the intergalactic medium, and how this impacts the properties of the intergalactic gas.

How is the escape of ionizing photons influenced by feedback?

Benedetta CIARDI (MPA Garching)

The fraction of photons emitted within a galaxy which is able to escape into the intergalactic medium (typically referred to as escape fraction) is one of the most uncertain quantities in theoretical models, as well as observations, of the reionization process. In this talk I will discuss how SN feedback affects the escape fraction using the SPICE radiation hydrodynamic simulations.

Early Galaxies and Black Holes under Cosmic Microscope

Marusa BRADAC (University of Ljubljana)

Gravitationally lensed galaxies provide a unique laboratory for determining star formation at ever-decreasing scales and studying the processes that shaped galaxy assembly. Recent observations with JWST indicate that even galaxies at the epoch of reionization have started forming stars in more compact clumps than previously thought. I will present the latest results from JWST cluster surveys (CANUCS, VENUS, Bullet), showing successful measurements of stellar population properties with scales < 10 pc and identifying new puzzles for future surveys with JWST and ELT.

Probing reionization using Lyman-alpha emitters

Girish KULKARNI (TIFR)

The discovery of Lyman-alpha emission from galaxies at redshifts approaching $z \sim 13$ is one of the remarkable results to emerge from JWST. Together with increasingly powerful surveys from Subaru and the prospect of observations with the Roman Space Telescope, these discoveries have renewed interest in an idea that goes back to the 1990s, of using Lyman-alpha emitters (LAEs) to probe the ionisation state of the intergalactic medium during cosmic reionisation. The challenge now is to determine how best to extract this information from the growing observational datasets. In this talk, I will explore a progression from traditional statistical probes to the reconstruction of the three-dimensional structure of reionisation. I will first show how the LAE bispectrum can reveal information about the morphology of ionised regions that is difficult to access through conventional statistics. I will then introduce TORRCH, a deep-learning framework based on U-Net neural networks, which enables the reconstruction of the neutral-hydrogen distribution from sparse samples of LAEs and UV-selected galaxies. Building on this approach, I will present new results from BISIP, a bias-guided stochastic-search method that uses forward-model consistency to select informative simulations and progressively improve the reconstruction. In tests involving astrophysical scenarios outside the initial training distribution, BISIP reduces the field-estimation error by approximately 65 per cent relative to a non-adaptive TORRCH baseline. Finally, I will discuss how assumptions about the intrinsic Lyman-alpha emission from galaxies can introduce systematic biases into estimates of the IGM neutral fraction. I will argue that these developments point towards an exciting possibility of moving beyond measurements of when reionisation occurred to reconstructing its three-dimensional structure.

Efficiency of cluster formation during early galaxy evolution

Andrey KRAVTSOV (University of Chicago)

I will briefly outline observational evidence for a large fraction of star formation occurring in massive bound clusters during early stages of evolution of the Milky Way and other galaxies. I will then present a model of star cluster formation that accounts for both the population properties of the Milky Way globular clusters and empirical estimates of cluster formation efficiency in JWST observations of galaxies at $z > 3-5$.

How to raise a supermassive BH: AESOPICA simulations

Sophie KOUDMANI (University of Hertfordshire)

The active black holes uncovered by JWST in the early Universe are highly abundant and seemingly overmassive with respect to local scaling relations, challenging standard models of black hole formation and growth. Yet it remains unclear whether they trace an efficient early growth channel, the observable tail of a broader population, or suffer from systematic uncertainties in mass estimates. I will present the AESOPICA project, a suite of twelve mid-volume cosmological simulations based on the FABLE galaxy formation model, varying the black hole seed mass across the theoretical formation channels, the accretion efficiency, including super-Eddington bursts, and the supernova feedback strength. We forward-model observational selection with BALMERSOPICA, a mock JWST broad-line survey pipeline that assesses the detectability of each simulated AGN for a given grating and exposure time. We find that the bulk of the JWST AGN population can be assembled from any seed mass provided the accretion efficiency is high, although light seeds require the most favourable accretion conditions explored. Applying broad-line selection naturally recovers the apparently overmassive population, with the detected AGN lying furthest above the intrinsic black hole mass – stellar mass relation for inefficient accretion models. The selected AGN lie on the local, weakly evolving black hole mass – stellar velocity dispersion relation, supporting a scenario where black holes assemble before the stellar component is fully established. Since efficient accretion rapidly erases the imprint of the initial seed mass, the low-mass end of the black hole mass function and host gas-phase metallicities offer the most promising discriminants between seeding channels.

The X-ray view of accreting SMBHs at Cosmic Dawn

Fabio VITO (INAF OAS Bologna)

X-ray emission is a nearly universal feature of accreting supermassive black holes (SMBHs), shining as active galactic nuclei (AGN), and carries key information on the accretion physics and geometry. Understanding such properties is particularly valuable at high redshift to understand how the first SMBHs formed and assembled their masses. In this regard, the recent discovery by JWST of sizeable populations of X-ray weak, or even silent, AGN at high redshift continues to puzzle the astronomical community, but offers a brand-new perspective onto SMBH formation and growth in the early Universe. I will overview recent X-ray observational results on high-redshift AGN, bridging the gap between luminous quasars and the new JWST-selected population, and I will discuss some ongoing efforts to explain the X-ray properties of the new X-ray weak population.

A Shining Cosmic Dawn

Stefano CARNIANI (SNS Pisa)

JWST has revealed an unexpectedly abundant population of luminous, blue galaxies at ($z > 10$), challenging our understanding of galaxy formation during the first few hundred million years of cosmic history. Their abundance raises fundamental questions about the efficiency of star formation, the role of feedback and dust attenuation, and the possible contribution of accreting black holes. We present JWST observations of spectroscopically confirmed luminous galaxies at $z=10-14$ identified in the JADES programme. These observations confirm that the bright end of the UV luminosity function evolves more slowly than predicted by many theoretical models. To investigate the physical processes behind this unexpected luminosity, we focus on JADES-GS-z14-0 at ($z=14.18$). New JWST/NIRSpec spectroscopy from the JADES and OASIS programmes reveals a striking difference in C III] emission despite consistent UV continua. Differences in shutter placement suggest that the line-emitting gas is displaced by approximately 400 pc from the stellar continuum, while NIRCам imaging constrains its spatial extent. Interpreting this diffuse, carbon-enriched gas as evidence of ongoing or past outflows, we infer a mass outflow rate exceeding 100 $M_{\odot}/\text{yr}$ and a mass-loading factor greater than two. The driving mechanism remains uncertain, and we cannot exclude an outflow launched during a previous episode of AGN activity. We discuss whether past activity from a now-dormant black hole could also help explain the apparent bimodality of galaxies at Cosmic Dawn in the size–NIR–luminosity plane. Finally, assuming that the outflow is driven by star formation, we constrain the instantaneous star-formation efficiency to below 10%. These results support a scenario in which moderate star-formation efficiency and reduced dust attenuation can account for the emergence of exceptionally UV-luminous galaxies at the highest redshifts.