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Review : 35 min
Keynote Presentation: 25 min
Contributed talk : 20 min
Poster Presentation : 5 min

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The Windows and Walls of the Labyrinth: Decoding Lyman-alpha Radiation

Abstract: The escape of Lyman-alpha (Lya) photons from galaxies resembles navigating a complex labyrinth shaped by the interplay of gas geometry, radiative transfer effects, and scattering dynamics. Although Lya is a useful tracer of both gas conditions and ionizing radiation, its resonant nature and the complexity of its radiative transfer make it challenging to relate observed profiles to the underlying physical conditions directly. Using Monte Carlo simulations, we explored Lya propagation in anisotropic media, including slabs with single and multiple channels, varying column densities, outflows, and dust, as well as different column density distributions such as lognormal and bi-modal shapes expected in the ISM. Regardless of the setup simplicity, the results are counterintuitive and far from simple. Surprisingly, most photons do not escape through low-column-density channels but undergo extensive scattering. Analytical modeling revealed that increased scatterings per reflection enhance overall transmission, suggesting that Lya photons trace an averaged hydrogen distribution rather than exclusively following paths of least resistance. From the radiative transfer perspective, I will discuss the implications of this behavior for Lya's escape from galaxies, considering the role of gas anisotropy and multiphase structures. These provide a different perspective on interpreting Lya observables and the connection with the transport of Lyman-alpha and -continuum through galactic labyrinths

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Production and potential escape of Lyman radiation in Extreme Emission-Line Galaxies from DESI

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Abstract: Lessons learned from detailed studies of low-redshift galaxies have unveiled the physical processes governing the production and escape of Lyman photons, offering essential emission-line diagnostics to interpret the properties of their counterparts at high-redshifts and their role in cosmic reionization. In this work, we apply these indirect diagnostics to identify reionization analogs within the unprecedentedly large and deep spectroscopic dataset of DESI. We present the physical characterization of a 20,000-object sample of extreme emission-line galaxies at z1 including objects with compact morphologies, high ionization conditions, and low metallicities. We will discuss the statistical power of such datasets to investigate the nature of extreme emitters, providing a crucial benchmark for comparison with JWST observations of reionization-era galaxies.

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Tracing ionizing escape potential in IZw18

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Abstract: Stellar feedback in star-forming galaxies can facilitate the escape of ionizing photons by driving outflows that carve low-density regions through the interstellar medium. In this work, we present new results on the ionized gas kinematics of IZw18 from the IFU MEGARA/GTC 10.4m. This is an extremely metal-poor galaxy known for its lack of detected Lyα or LyC escape, to explore whether outflows might ultimately enable ionizing radiation to escape. Our spectroscopic analysis of the HeII4686 emission line reveals an asymmetry profile consistent with an off-centered blueshift outflow along the line of sight. This suggests an early onset of a stellar-feedback-driven outflow that is still in the inner part of the galaxy. Although IZw18 currently shows no direct evidence of Lyα or LyC leakage, we propose that, depending on the amount of material this internal blueshifted outflow encounters along its path, it could eventually open a channel for ionizing photons in a close direction to the line of sight. These results highlight the pivotal role of feedback-driven kinematics in shaping the escape of ionizing radiation, underscoring the need for deeper and more spatially resolved observations to confirm outflow geometry, quantify its impact on escape fractions, and place IZw18 in a broader evolutionary context.

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How WST, the Wide-Field Spectroscopic Telescope, could revolutionize the study of Lyman-alpha galaxies

Abstract: Significant progress has recently been made in the detection and study of Lyman-alpha emitters (LAEs) and their circumgalactic medium (CGM) at high redshift. However, the story is far from complete. Understanding the complex behavior of Lyman-alpha radiation and its relationship with galaxies and their environment requires substantial theoretical and observational efforts. On the observational front, the Wide Field Spectroscopic Telescope (WST) will offers groundbreaking potential. Combining the power of a 12-meter-class telescope with a highly multiplexed multi-object spectrograph (MOS) and an immense integral field spectrograph (IFS), WST is poised to revolutionize this field. Proposed as the next major ESO project following the ELT, WST will deliver the unprecedented sensitivity and large-scale statistical power needed to probe Lyman-alpha radiation across different environments and different scales—from galactic and circumgalactic structures to the intergalactic medium. In this talk, I will introduce WST and discuss how it could transform our understanding of Lyman-alpha radiation, enabling tens of millions of measurements and unlocking new insights into the interactions between galaxies and their environments.

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Searching for the galaxies that reionized the Universe: Lyman Continuum emitters at z > 3

Abstract: Galaxies likely drove the reionization of the IGM in the early universe, but ionizing flux from galaxies in the epoch of reionization cannot be observed directly due to the opacity of the IGM, making it difficult to determine which galaxies contributed most of the ionizing radiation (Lyman continuum, LyC). Whilst several diagnostics have been found to trace LyC emission in the local universe, it is unclear to what extent these are valid at higher redshifts. I will discuss two programs addressing this by targeting LyC emitters at $3<z<4$. These galaxies are seen shortly after reionization and are among the earliest galaxies for which LyC emission can be observed.

First, Ion3 is the most distant confirmed LyC emitter, at $z=3.99$. Ion3 shows a `clumpy’ morphology, as well as a variety of emission lines that suggest a high star-formation rate and a highly-ionized interstellar medium, conditions similar to those in low-z LyC emitters. Second, the Parallel Ionizing Emissivity (PIE) survey is a HST program targeting 60 independent fields to build a statistical sample of $3<z<3.5$ galaxies that can be stacked to reveal how their LyC emission varies with galaxy properties. Independent fields will allow us to average over variations in the IGM opacity, and directly compare LyC escape between local and high-redshift galaxies for the first time. Confirming the reliability of LyC indicators shortly after reionization is the next step towards observing and understanding the galaxies that drove the reionization of the IGM.

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LyC Escape and IGM Tomography Using the 600-900Å Continuum of the Sunburst Arc

Abstract: The Sunburst Arc (z~2.37) is a confirmed Lyman continuum leaker galaxy and has been uniquely lensed where its single leaking region is imaged 12 times over four separate arcs. Using HST/WFC3 UVIS G280 grism observations, we extracted the spectra of the leaking region to determine the shape of the stellar continuum from 600-900Å (produced by young, massive O and B stars) for the first time. The intrinsic Lyman continuum escape fraction is >70% leaving the interstellar medium, but foreground intergalactic medium (IGM) absorption lowers this estimate to ~30%. The same foreground IGM absorbers at z~2 are seen in multiple images, allowing us to constrain their physical size in 2D and estimate their HI mass. This rare sightline gives insight into the conditions necessary for the propagation of ionizing photons and can help interpret results from reionization.

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Could we improve our galaxy size measurements at very high redshift?

Abstract: Long story short, no. Cosmological dimming goes as (1+z)^3 when working with flux densities, ergo decreasing the surface brightness of our observations over redshift by +7.5*log10(1+z). And there are other additional problems (CMOD effect, change of physical scale). Moreover, we are biased towards light concentration, as our traditional size proxy is the effective (half-light) radius. However, we can do better for low-z observations, by using the radial location of the gas density threshold for star formation, i.e. galaxy edges/truncations. Even though these are low surface brightness features, the mass density at which these truncations appear in our data increases over redshift, helping their detectability. This fact resembles the more active star formation conditions at the redshifts where galaxies formed and gives us hope to find those galaxy edges/truncations beyond the intermediate redshift Universe. Finally, as we are speaking of features related with star formation, they should be more easily observable in Halpha or in the UV-restframe. Therefore, this will be a provocative contribution to promote debate about unforeseen ways to improve our size measurements and to reflect about the validity of the tiny sizes we are finding at z>5-10.

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Mapping the ISM conditions of local analogs of primeval galaxies

Abstract: To understand cosmic reionization and shed light on the main drivers of this process, it is essential to investigate how ionizing radiation escapes from galaxies. In this context, spatially resolved observations using Integral Field Spectroscopy are key to scan the inhomogeneities of the ISM and identify optically thin channels through which the Lyman Continuum (LyC) photons may escape. In this talk, I will present the first results of a 2D spatially-resolved study of local analogs of high-z galaxies performed with MEGARA/GTC. We compared the general properties of our local galaxies with JWST observations of sources at $z > 7$, reinforcing their status as excellent reionization-era analogs. We then investigated the predominant ionization mechanism of these galaxies and traced sub-kpc variations of their physical properties. Taking into account that the escape of LyC photons is a multiparameter problem, we mapped the ionizing structure of the ISM using several indirect indicators of LyC leakage. Finally, we estimated the escape fraction of ionizing radiation in different regions of the galaxies and found significant spatial variations, a signature of the ISM porosity.

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Does Radiation or Supernovae Feedback Drive LyC Escape?

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Abstract: Feedback plays a critical role in enabling Lyman continuum (LyC) escape in star-forming galaxies, but the processes by which outflows clear neutral gas and dust remain unclear. In this talk, we present on our work to model the Mg II 2796Å, 2804Å absorption + emission lines in 29 galaxies taken from the Low-z LyC Survey to investigate the impact of (radiation + mechanical) feedback on LyC escape. Using constraints on Mg+ and photoionization models, we map the outflows' neutral hydrogen content and predict fesc with a multiphase wind model. We use SED template fitting to determine the relative ages of stellar populations, allowing us to identify radiation feedback dominant systems. We then examine feedback related properties (stellar age, loading factors, etc.) under conditions that optimize feedback efficiency, specifically high star formation rate surface density and compact UV half-light radii. Our findings indicate that the strongest leakers are radiation feedback dominant, lack Mg II outflows, but have extended broad components in higher ionization lines like [O III] 5007Å, as observed by Amorín et al. (2024). In contrast, galaxies experiencing supernovae feedback typically exhibit weaker fesc and show evidence of outflows in both Mg II and higher ionization lines. We attribute these findings to enhanced LyC escape facilitated by turbulence and cloud fragmentation in intense radiation fields, prolonged in low-metallicity environments experiencing delayed supernovae.

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Lyα Radiative Transfer in Turbulent Medium

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Abstract: Turbulence plays a crucial role in various astrophysical phenomena, from star formation to galaxy evolution, influencing the gas properties. Lyman Alpha (Lyα) is one of the most prominent emission lines in diverse astrophysical objects. Due to its resonance nature, the physical properties of cold gas are imprinted on Lyα emission features. Many radiative transfer simulations have been developed to explore how Lyα delivers the physical properties of the cold gas, including turbulence. However, most simulations treat the turbulent motion as 'microturbulence,' which is simplified turbulence assuming a Gaussian velocity distribution without spatial correlations. In this work, we investigate the impact of realistic turbulence on the formation of Lyα by combining the Lyα radiative transfer simulation 'RT-scat' and hydrodynamic simulations to generate turbulence. In this presentation, I will show the simulated Lyα spectra from the media with realistic turbulence and compare them with their microturbulence counterparts, demonstrating that the Lyα spectrum of realistic turbulence differs from that of microturbulence. I will also determine that realistic turbulence leads to significant temporal and directional variations in the Lyα spectrum, highlighting the importance of turbulence in the formation of Lyα. In addition, I will discuss how to fully capture and treat optically thick turbulent gas in Lyα radiative transfer for large-scale simulations.

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Illuminating the Escape from the Galactic Labyrinth Through X-rays

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Abstract: Bright X-ray sources are strong candidates in explaining Lyman photon leakage from low metallicity (low-Z) starburst galaxies. High-mass X-ray binaries and superbubbles can dominate over massive stars and super star clusters as as the main contributors of ionizing emission within a galaxy. Therefore, multiwavelength studies utilizing deep X-ray data alongside Optical, UV, and IR observations are essential in understanding the origins of the ionizing power. I will show how our new Chandra and XMM-Newton observations of the blue compact dwarf galaxy ESO 338-4, a nearby analogue of high redshift starbursts, are invaluable in determining the primary production sites of ionizing radiation in low-Z galaxies. I will explore the spectra of the galaxy's X-ray population as well as the galactic halo's diffuse emission. These results improve our understanding of Lyman radiation production, highlighting the importance of considering X-ray sources alongside massive star populations. X-rays are therefore Ariadne's thread, guiding us in explaining the escape from the galactic labyrinth.

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Investigating LyC Production and Escape in Local Metal-Poor Dwarf Galaxies

Abstract: The UV luminosity functions (LFs) of galaxies observed at high redshift (z) indicate that numerous UV-faint, star-forming galaxies may produce enough ionizing photons to drive cosmic reionization. Theoretical models also suggest that less massive halos were the primary contributors of ionizing photons to the intergalactic medium during the epoch of reionization. A key open question is how faint the reionizing galaxy population extends, assuming dwarf galaxies were indeed the main drivers of cosmic reionization. Most reionization models adopt a faint-end cut-off magnitude of the UV LF at Muv = -13 as a fiducial limit for computational purposes. However, this choice is somewhat arbitrary, as there is no physical justification for a sharp cut-off in the UV LF. Thus, it is essential to explore the potential contribution of galaxies with magnitudes extending across a broad range around this nominal cut-off, including those too faint to be detected even by JWST at $z > 6$. In this talk, I will introduce a novel approach to derive the LyC production rate and escape fraction for galaxies using resolved stellar populations. Additionally, I will present preliminary results toward the first measurements of LyC production rates and escape fractions for UV-faint, metal-poor, star-forming dwarf galaxies in the Local Volume. These results aim to shed light on the faint end of the reionizing galaxy population and their contribution to the ionizing photon budget.

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Shedding light on the escape of Lyman continuum and Lyman alpha photons in the JWST, Euclid and SKA era: implications for reionization

Abstract: The past few years have seen cutting-edge instruments such as the James Webb Space Telescope (JWST) provide tantalising glimpses of early Lyman Alpha emitting galaxies assembling in an infant Universe. Puzzlingly, these observations are also yielding a sample of unexpectedly numerous and large black holes (up to a 100 million solar masses) within the first 600 million years. These are allowing first constraints on the source population for reionization within the first billion years. This is supplemented by data from the Atacama Large Millimetre Array (ALMA) yielding direct hints on the dust contents of early sources, crucial to understanding the escape fractions of both ultra-violet and ionizing radiation. Finally, these are being complemented by low-redshift surveys directly measuring the escape fraction of ionizing photons, a key unknown in the reionization process. The talk will focus on showing how these datasets provide an unprecedented opportunity to shed light on the the escape of Lyman continuum and Lyman alpha photons, and pin down the reionization state and its key sources, crucial for the forthcoming SKA era.

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Extreme UV emitting Lyman Continuum leakers at the Cosmic Noon

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Abstract: One of the outstanding problems of current observational cosmology is to understand the nature of sources that produced the ionizing radiation after the Cosmic Dark Age. Due to the steep decline of intergalactic medium transmission, direct detection of these reionization sources is difficult at high redshift. The FUV band of the Ultraviolet Imaging Telescope (UVIT) onboard AstroSat with rest-frame Lyman limit of hydrogen at 912 Å from z∼0.97, is ideally suited for such detections. Here we present Lyman continuum (LyC) emitters detected at redshift z~1.2-1.6 in the Astrosat Ultradeep Deep Field North using UVIT. This forms the first coherent sample of LyC leakers at z∼1-2 as there were no direct detections at z∼0.5-3 earlier. This research bridges the gap between GALEX and Cosmic Origins Spectrograph (COS) at low-z, and HST WFC3 at high-z and stands crucial in understanding the evolution of LyC leakers. These sources emitting Extreme Ultraviolet radiation at a rest-frame wavelength of ~600 Å would be essential in constraining the shape of the ionization spectrum. We present the properties of the LyC leakers sample as derived from the SED fitting with the addition of the EUV wavelengths, and their dust and ISM properties. For some of the LyC leakers, the LyC radiation is found to be significantly offset from the UV Continuum and optical centres. Using the Halpha emission line maps and UV continuum morphology, implications of the offsets in the LyC radiation will be discussed.

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ISM properties in and around candidate LCEs with nebular He II emission

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Abstract: The study of local Lyman Continuum Emitters (LCEs) serves as a promising proxy to understand the mechanisms driving Lyman Continuum photon leakage during the Epoch of Reionisation. In the search for such candidates, in 2023 we reported a sample of eighteen low-redshift, low-metallicity and highly ionised dwarf galaxies. These objects are highly intriguing due to the unclear origin of their nebular He II emission, and a recent two-stage starburst serves as a compelling explanation for the LCE nature of these objects, as the cumulative effect of recent supernovae (SNe) redistributes an appreciable fraction of the ISM in these low-mass systems. Having obtained long-slit spectra with an 8m class telescope for an appreciable subset of this sample, we now move on to an in-depth analysis of these galaxies, unveiling their star-formation histories and ISM properties, while providing a more thorough discussion of the ionising agents. A particular emphasis will be placed on the ionisation structure and circumgalactic emission, further informing our SNe hypothesis and discussing the role of galactic outflows driven by a population of young, metal-poor stars.

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Little Red Dot Analogues at Low-redshift: A Window into AGN Ionisation at Cosmic Dawn

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Abstract: Active galactic nuclei (AGN) are thought to play a key role in the reionisation of the Universe, acting as a major source of hard ionising photons during the cosmic dawn. Moderate-luminosity AGN, the most numerous class during this epoch, have been recently identified as 'Little Red Dots' by deep JWST surveys. However, their ionisation properties remain poorly characterised due to observational constraints. To address this, we present a sample of over 500 local analogues (z 1), selected through k-means clustering of DESI EDR spectra, which closely mirror the colours and spectral properties of early AGN. New emission-line ratio diagnostics based on [OIII]4363 and [NeV]3426 allow us to disentangle AGN photoionisation from star-forming activity, specifically addressing the challenges of low-metallicity, high-ionisation environments prevalent in the early Universe. Using this sample, we characterise the Lyman continuum emission and ionising photon production rates, providing constraints on the escape fraction of Lyman radiation for these sources. These results are compared with those obtained for the AGN population at high-z. The study of Little Red Dot analogues at low-z offers a robust framework for understanding the contribution of black hole accretion to cosmic reionisation. These analogues yield valuable insights into the mechanisms driving Lyman photon escape and the role of AGN in shaping the properties of the interstellar medium during the reionisation epoch.

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The beautiful Confusion: Super-early Galaxies seen by JWST

Abstract: One of the major surprises provided by the first years of early Universe observations by JWST has been the detection of a stunning overabundance of luminous, and likely massive, galaxies at redshift z>10. As the first spectroscopic confirmations are accumulating, it is crucial and timely to investigate these important and yet unknown aspects of early galaxy formation and evolution. At a time at which ALMA has laid the foundations of our understanding, Webb seems to hint at a possibly conflicting scenario. These (apparent?) contradictions need to be solved in the framework of studies that combine theory, cosmological simulations and the most advanced IR/sub-mm observations. I will analyze the possible new scenarios and propose some preliminary answers to the above questions.

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ODIN: Investigating the Star Formation Histories and Radiative Transfer of LAEs at Cosmic Noon

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Abstract: Lyα Emitting (LAE) galaxies are often used for large-scale statistical analyses, however, there is still much we do not understand about their physical nature. The ODIN program uses three DECam narrowband filters to discover LAEs at z ~ 2, 3, and 4. In Firestone et al. 2024, we introduced improved techniques for narrowband LAE selection and interloper rejection. We presented stacked SEDs and Lyα EW distributions, which were best fit by exponentials with scale lengths of 53, 65, and 59 ±1Å, respectively. In Firestone et al. 2025, we used ODIN LAEs and UVCANDELS photometry to test the conventional assumption that LAEs are experiencing their first major burst of star formation at the time of observation. We accomplished this using the Gaussian process-based non-parametric star formation history (SFH) reconstruction method, Dense Basis. We found that a strong majority (67%) of our LAE SFHs align with the conventional archetype of a first major SF burst. However, 28% exhibit earlier bursts of SF despite the ongoing burst having the highest SFR, and the final 5% experienced their highest SFR in the past. Subsequently, we characterize Lyα radiative transfer for each LAE. We find that the majority of LAEs experience an enhancement of Lyα photons relative to UV continuum photons, in some cases consistent with the clumpy dust hypothesis. Overall, our results suggest that several evolutionary paths and radiative transfer mechanisms can produce galaxies with strong observed Lyα emission.

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Clearing the Path to Cosmic Reionization: New Insights from HST and JWST

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Abstract: Observations such as the Gunn-Peterson trough indicate that the Universe reionized by a redshift of z~6. However, we cannot directly identify the galaxies responsible for this dramatic change in the intergalactic medium (IGM) because the ionizing photons involved were lost in the process of Reionization. Instead, we must rely on observations of ionizing radiation (Lyman continuum or LyC) from nearby (z~0.3) galaxies analogous to galaxies at z>6 in order to establish observational proxies for LyC escape at high redshift. I will present the Low-redshift Lyman Continuum Survey (LzLCS), a large HST/COS program with the most local LyC measurements to date, to investigate LyC escape at z~0.3. With the LzLCS results, I will illustrate which nearby analog galaxies are the most significant LyC emitters (LCEs) and which physical mechanisms facilitate LyC escape into the IGM at z~0.3. I will also present the first ever JWST/MIRI MRS observations of nearby confirmed LCEs, characterizing the multiphase ISM with new insights into the dust and PAH content in nearby galaxies leaking ionizing photons.

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Probing the Physics of Lyman Alpha Escape using High-Redshift Lyman Alpha Emitters

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Abstract: High-redshift galaxy surveys allow us to probe the physics of the first galaxies and their interaction with the intergalactic medium (IGM). Lyman-Alpha emitters (LAEs) are of particular interest since the Lyman-Alpha (LyA) line traces both intragalactic physics–including the state of the interstellar medium (ISM), the presence or absence of inflows and outflows, and the stellar initial mass function–as well as extragalactic physics via the attenuation of LyA emission in resonance with the IGM. Recent surveys targeting the LyA line have published statistics at high redshifts, allowing forward modelers to constrain the history of reionization by attempting to reproduce these statistics. However, these constraints have thus far been made under the assumption of a fiducial relationship between intragalactic parameters and intrinsic LyA emission. This relationship, while reasonable at redshifts post-reionization, has not been validated for galaxies at the highest-redshifts, and may introduce bias in the inferred ionization history if incorrect. In this study, we introduce a parameterised relationship between galaxy parameters and LyA intrinsic emission, and allow the parameters of this relationship to vary along with the IGM ionization state, thus allowing us to quantify the degeneracy between intrinsic emission and environmental occultation in reproducing the equivalent width distribution and luminosity function of high-redshift LAEs.

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Search and characterization of low-z analogs to reionization galaxies in J-PAS

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Abstract: Local galaxies with extreme emission lines (EELGs) provide crucial insights into cosmic reionization, serving as low-redshift analogs to their high-redshift counterparts. As large sky surveys become more prevalent, the challenge of identifying these objects grows due to the sheer volume of data generated. For example, J-PAS will survey 8,500 square degrees with 56 narrow-bands filters from 3500A to 9500A, emphasizing the need for Artificial Intelligence (AI) to efficiently search and characterize EELGs within massive datasets. In this study, we present the first analysis dedicated to identifying and characterizing galaxies with exceptionally large equivalent widths using the first internal data release of J-PAS (30 square degrees, 56 filters). Our search has yielded nearly 1,000 EELG candidates, for which we derive key physical properties, including ionizing photon production, luminosity, stellar mass, and size. Finally, we will discuss the potential of J-PAS and synergies with other datasets for detailed statistical analyses of EELGs at z<1.

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Ionizing Photon Escape in the Epoch of Reionization: Insights from JWST NIRSpec observations

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Abstract: The Epoch of Reionization (EoR) represents the Universe's last major phase transition, when the neutral intergalactic medium (IGM) became ionized likely driven by photons escaping from early galaxies. Direct observation of the ionizing flux during the EoR is impossible due to IGM opacity. However, a high escape fraction of ionizing photons (fesc) leaves clear imprints in the spectra of galaxies, such as bluer UV continuum slopes and reduced nebular line emission. Here, we exploit the large archive of deep JWST/NIRSpec spectra from the RUBIES survey and the DAWN JWST Archive to analyze over 850 galaxies at z>4 and constrain their fesc based on SED fitting enhanced with a picket fence model. We identify 37 high-confidence sources with significant fesc based on Bayes factor analysis strongly favoring fesc>0 over fesc=0 solutions. We compare the characteristics of this high-escape subset against both the parent sample and established diagnostics including beta slope, O32, and SFR surface density. For the overall sample, we find that most sources have a low escape fraction (1 however, a small subset of sources seems to emit a large number of their ionizing photons into the IGM, such that the average fesc is found to be 10-20%, as needed for galaxies to drive reionization. Our identification of individual Lyman continuum leakers during the EoR demonstrates JWST/NIRSpec's capability to provide direct constraints on the drivers of cosmic reionization.

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Characterizing the extended Lyman-alpha emission around high-redshift massive galaxies

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Abstract: The circumgalacitc medium (CGM) is the gas reservoir enveloping a galaxy beyond its interstellar medium but within its halo. The CGM is an interface of gas exchange between a galaxy and its surroundings (inflows/outflows). Studying the physical processes shaping the CGM is then key to understand galaxy formation and evolution. Observations of the CGM are now routinely reported around high-redshift (2<z<6) quasars as extended Lyman-alpha (Lya) emission, which traces the cool T~10^4 K gas out to the expected virial radius (R~100 kpc) of the hosting halos (M~10^12.5 Msun). While most studies focused on the Lya emission around the brightest systems, targeting the full quasar population down to the fainter objects would allow one to unveil how the CGM responds to the different quasar activity. In this contribution, I will present new VLT/MUSE observations of 120 quasars at z~3, covering the full range of SDSS luminositites. I will discuss how the discovered Lya nebulae surface brightness, morphology and kinematics vary as a function of quasar properties, such as bolometric luminosity and black-hole mass. This survey has now enough statistics to study the impact of AGN feedback while controlling for black hole properties (e.g., mass), which will be key to constraining AGN models. I will conclude by describing a simple scenario that can explain the observed trends.

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The escape of Lyman-α photons and the contribution of Lyman-alpha emitters to reionisation

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Abstract: We present new results on the escape fraction of Lyman-alpha photons from a large sample of Lyman alpha emitters (LAEs) towards the epoch of reionisation, detected by MUSE and imaged by both HST and JWST. We focus on gravitationally-lensed galaxies to target the faint galaxy population likely to be responsible for the majority of the reionisation process. We derive the escape fraction using two methods: the comparison of dust-corrected star formation rates (SFRs) and Lyman-alpha SFRs in individual galaxies and the comparison of the two state of the art luminosity functions (LFs: UV and LAE) in lensing fields. When treating individual galaxies, we find a negligible redshift evolution of the escape fraction, which highlight the existence of a wide variety of escape scenarios, even in galaxies selected by their Lyman-alpha emission. In stark contrast, we observe a significant evolution with UV magnitude, confirming that fainter galaxies allow Lyman-alpha photons to escape more easily, and that this does not change significantly over our redshift range (2.9 to 6.7).
The luminosity function comparison shows a stronger trend with redshift, and when we integrate down to MUV~-13 and a Lyman-alpha luminosity of 10^39, which we are able to do for the first time without extrapolation of the LF, the Lyman-alpha escape fraction is consistent with 100% at z~6, indicating that these low-mass, highly star-forming galaxies are allowing huge quantities of Lyman-alpha photons to escape.
In light of this, we also present calculations of the LAE contribution to the reionisation process using well-motivated values of the ionising photon production efficiency and the escape of Lyman continuum photons, showing that these galaxies likely played an important role in reionisation, potentially contributing up to 100% of the photons needed at z~6.

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Stellar sources that produce ionizing radiation

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The escape fraction from galactic labyrinths of ionizing photons produced by high-z AGNs

Abstract: The hydrogen reionization is a key phase transition of the Universe, being a sharp and late cosmological event ending at z~5.3. The main leading candidates for the production of Lyman Continuum (LyC) radiation are still a mystery, with two main suspects, i.e. star-forming galaxies and AGNs. The high AGN number fractions recently revealed by JWST, together with the large LyC production efficiency and leakiness into the intergalactic medium (IGM), typical of bright UV-selected AGNs, lead us to assess a scenario where AGNs are the main drivers of the cosmic hydrogen/helium reionization processes. In this talk, a summary of the main results from recent observations on the escape fraction of HI ionizing radiation produced by high-z AGNs will be discussed, together with some hints on the physical processes at play from cosmological simulations. Some highlights will be provided on the future observational facilities that will help astronomers to understand how ionizing photons produced by high-z AGNs are able to escape from those intricate galactic labyrinths.

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Lyman continuum escape from intergalactic star clusters

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Abstract: Multiple observations show that cold gas clouds exist in the intergalactic space. This gas can be stripped-off by ram pressure (RP) from low-mass to massive galaxies on their passage through the intra-cluster hot gas (IGM) in galaxy clusters, be expelled in tidal arms of galaxy encounters, or be just condensed by cooling and self-gravity effects from an inhomogeneous IGM. For all these scenarios observational evidence exist that star clusters (SCs) can be formed in these intergalactic clouds. In the case of RP-stripped clouds the SCs continue to move with the cloud velocity at formation while their gaseous envelops as further accelerated by the drag depart from the SC, leaving them behind as "naked" within the IGM. Since the timescale of this gas removal is short, massive stars are still alive, but their Lyman continuum (LyC) photons cannot be fully consumed to ionize this gas envelop to emit H-alpha and escape from the SC. The naked massive stars are also observable in FUV and NUV. The VESTIGE survey of the Virgo galaxy cluster (VC) provides a wealth of deep H-alpha observations, of which also RP-stripped gas is detected. The RP-stripped VC spiral galaxy NGC 4254 with its rich number of extragalactic SCs can serve as ideal target, in which the clearing process of SCs from their native clouds can be studied in detail. From derived ages and the partly emitted H-alpha, the fraction of lost Lyc photons can be derived. For the naked SCs the actual Lyc escape can be calculated.

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On the model dependence of the ionizing photon production efficiency. What are we really measuring?

Abstract: Modern instruments are quickly eliminating the observational constraints once limiting our understanding of the early universe. The JWST has populated high redshift catalogues with deep rest-optical and IR photometry while increasingly sophisticated SED modelling tools interpret the underlying ionizing photon production (ξ_ion) and its escape (f_esc). The interface of observations and models, however, is complex and our interpretation of the data relies deeply on the applied star, gas and dust models. We've observed that parametric bursty vs simple SFH models can change ξ_ion by more than 0.5 dex, which completely redefines the reionization budget and timeframe. Similarly, the type of data used can shift the ξ_ion by more than 1 dex for the same galaxy and change the perceived relationship with redshift completely. Which method and models are best, what is the redshift relation, and what do modern large-volume cosmological radiation-magneto-hydrodynamic simulations of the EoR have to say about our observational methods? I will explore this using unique samples across our Universe's history to understand where our existing methods lie in the face of the deepest observations.

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UV Slopes of the Faintest High-Redshift Galaxies with Glimpse

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Abstract: The first structures in the universe produced enough ionizing photons to drive cosmic reionization. Since observations have yet to probe the faintest galaxies, it is still debated whether faint or bright galaxies produced the required ionizing photons. The rest-frame ultraviolet (UV) continuum slope (beta) is a critical diagnostic of star-forming galaxies and a key indicator of the escape of ionizing photons at high-redshift. We expand upon previous work with data from JWST's Glimpse, a program leveraging ultra-deep imaging and strong gravitational lensing of massive foreground cluster Abell S1063 to probe the faintest and highest redshift galaxies. We calculate UV slopes of ~250 high-redshift (z > 6) galaxies with absolute magnitudes down to MUV ~ -10. We find a constant evolution of beta with redshift and uncover a turnover in the beta-MUV relation, where beta gets bluer until MUV ~ -17 and becomes redder towards fainter galaxies. We estimate the Lyman continuum escape fraction (fesc) for each observed beta according to the empirical trend derived at low-redshift, finding fesc peaks at ~10% for these moderately bright galaxies (MUV ~ -17) with blue UV-slopes. We fit Bagpipes models which allow for a non-zero fesc to understand the origin and physical conditions which facilitate extremely blue UV-slopes. We provide new constraints on the ionizing photon budget from the faintest galaxies and discuss impacts for the timescale of cosmic reionization.

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Probing Lyman-Continuum Escape in Low-Redshift Dwarf Galaxies with HST UV Observations

Abstract: I will highlight two key HST studies investigating Lyman-continuum (LyC) escape from local analogs of high-redshift galaxies. First, I will present HST imaging observations of gravitationally lensed, intrinsically faint galaxies at $z = 1.3 - 3.0$. Contrary to expectations, these observations reveal no significant detection of LyC flux, challenging the prevailing assumption that UV-faint sources exhibit higher LyC escape fractions. These findings underscore the necessity of larger sample sizes to account for potential anisotropic LyC escape. Additionally, I will discuss an HST spectroscopic study of local compact star-forming galaxies with high [OIII]/[OII] ratios (>20), closely resembling the extreme emission-line properties of reionization-era galaxies. These local analogs exhibit intense CIV emission (EW > 10Å) and high CIV/CIII] ratios ($\gtrsim$1), signaling hard ionizing radiation and significant LyC leakage. We further examine the relative C/O abundances of our sample with literature measurements from reionization-era galaxies, placing them within a low-metallicity and low-C/O-abundance regime. The increased prevalence of such extreme galaxies in the epoch of reionization highlights their critical role in understanding ionizing sources and the chemical evolution of early galaxies.

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Lyα Emission at z=5-14: Evolution of the Lyα Luminosity Function and a Late Sharp Reionization

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Abstract: We present the statistical properties of Lyα emission in 586 galaxies at z = 4.5 − 14.2, observed by multiple JWST/NIRSpec spectroscopy projects, including JADES, GLASS, CEERS, and GO/DDT programs. We obtain Lyα equivalent width (EW), Lyα escape fraction, and ionizing photon production efficiency measurements or upper limits for these galaxies, and confirm that the Lyα emitting galaxy fraction decreases towards higher redshifts. We derive Lyα luminosity functions from z~5 to z~10−14 with the observed Lyα EW distributions and galaxy UV luminosity functions, and find a ∼3 dex decrease in number density at L_Lyα=10^42−10^43 erg s^−1 over the redshift range. We obtain the neutral hydrogen fractions of x_HI~0.17, 0.63, 0.79, and 0.88 at z∼6, 7, 8−9, and 10−14, respectively, via comparisons of the reionization models developed by semi-numerical simulations with 21cmFAST explaining the observations of Lyα, UV continuum, and Planck electron optical depth. The high x_HI values over z∼7−14 suggest a late and sharp reionization, with the primary reionization process occurring at z∼6−7. Such a late and sharp reionization is not easily explained by either a clumpy inter-galactic medium or sources of reionization in a classical faint-galaxy or a bright-galaxy/AGN scenario, unless a very high escape fraction or AGN duty cycle is assumed at z∼6−7.

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The Evolution of Lyman Alpha Width at the End of Reionization

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Abstract: Understanding the ionization state of the intergalactic medium (IGM) during the epoch of reionization (EoR) is fundamental to our comprehension of galaxy formation and evolution in the early Universe, but when and how reionization occurred is still yet to be constrained. Lyman alpha emission lines serve as effective indicators of a neutral IGM because they are resonantly scattered by neutral hydrogen. We mainly analyze the 15 Lyman alpha emitters (LAEs) at $z > 7$ in the GOODS-N field identified by Jung et al. (2020). We confirm that the more luminous LAEs show a broader Lyman alpha line profile than the fainter counterparts. The Lyman alpha emission profile can give us a hint into how Lyman alpha photons escape from their production in star formation. To uncover the underlying physics, we use the intergalactic medium (IGM) transmission calculation of Park et al. (2021) from the Cosmic Dawn II (CoDa II) simulation (Ocvirk et al. (2016)). We introduce the relative transmitted ratio to quantify how effectively the interstellar medium transmits Lyman alpha radiation compared to the end of the epoch of reionization.

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Comprehensive JWST+ALMA Study on the Extended Lya Emitters Himiko and CR7 at z∼7

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Abstract: We present various properties of two bright extended Lya objects, Himiko and CR7, at z=6.6 thoroughly investigated with JWST/NIRCam photometry, NIRSpec-IFU spectroscopy, and ALMA data, uncovering their physical origins. Himiko (CR7) shows at least five (four) clumps with small separations and velocity offsets of dv220 km/s in the [OIII]4959,5007 line maps, three of which exhibit stellar components with comparable stellar masses ranging in log{(M*/Msun)}=8.4-9.0 (8.3-8.8), indicative of major merger systems that are confirmed by our numerical simulations. The [CII]158um and Lya lines are found in the middle of two clumps (the brightest clump) in Himiko (CR7), suggesting that the distribution of neutral gas does not always coincide with that of ionized gas or stars in the merging processes. We find that some of the clumps have [OIII] broad (~300 km/s) components in Himiko and CR7, likely outflow and tidal features, while the central clump in Himiko presents a broad Ha (~1000 km/s) line explained by an AGN with a low-mass black hole of M_{BH}=10^{6.6} Msun, which contribute to the extended and bright nature of Himiko/CR7. We find low metallicities of 12+log(O/H)~8.0 in Himiko/CR7 based on [OIII]4363 and strong lines that are consistent with no 1-mm continuum detection corresponding to the dust mass limits of 9*10^6 Msun. Himiko/CR7 are metal- and dust-poor blue merger systems with stellar and dust masses >2 orders of magnitude smaller than the massive dust-rich merger systems.

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Effects of cosmic rays on ionized gas in AGN and starburst galaxies

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Abstract: Cosmic Rays (CRs) in active galactic nuclei (AGN) are a potential source of feedback able to regulate star formation. These non-thermal particles, accelerated by shocks, penetrate deep into the molecular gas, driving the heating and chemistry of the interstellar medium (ISM), and launching massive outflows. We examine the impact of CR feedback on ionized gas in a sample of nearby AGN and starburst galaxies. Using Cloudy photoionization models, we investigate CR effects on nebular gas, focusing on densities ($1–10^4$ cm^{-3}), ionization parameters ($-3.5 \le \log U \le -1.5$), and CR ionization rates ($10^{-16}–10^{-12}$ s^{-1}). Our models, compared with MUSE observations of Centaurus A, NGC 1068, and NGC 253, reveal that high CR rates ($\gtrsim 10^{-13}$ s^{-1}) can alter the thermal structure of ionized gas. Our study unveils that high CR rates, as those expected in AGN and strong starbursts, can induce a secondary ionization layer beyond the photoionization-dominated regions, enhancing the emission of low-excitation lines such as [NII], [SII], and [OI]. AGN models with CRs reproduce the Seyfert locus in BPT diagrams without super-solar metallicities, contrasting pure photoionization models, whereas star-forming models can explain non-AGN sources in the LINER region. Finally, we suggest new maximum BPT limits to differentiate regions dominated by AGN from star forming areas also impacted by high CR rates. Overall, our findings illuminate how AGN and supernova-produced CRs shape ISM in the local universe.

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Properties of Lya and non-Lya emitters at the epoch of reionization

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Abstract: Understanding the epoch of reionization (EoR) is one of the frontier goals of modern astronomy. Lyα emission from the high-redshift galaxies has proved to be a useful tool for probing cosmic reionization. The launch of JWST has enabled the ultraviolet and optical spectroscopic studies of Lyα emitters (LAE) in the EoR. In this contribution, we present the results based on the stacking analysis of JWST/NIRSpec spectra of galaxies taken as part of the JWST GTO program JADES. The sample consists of $>$250 galaxies at redshifts of $\sim$5-10. We divide this sample into six different sub-samples of galaxies based on the strengths of Lyα emission and redshifts and create composite spectra. We then estimate emission line ratios of optical and UV emission lines, and various physical quantities such as dust extinction, electron temperatures, ionization parameters, and ionizing photon production efficiencies to characterize the populations of LAEs and non-LAEs. Our analysis shows that Lyalpha emitters have a harder radiation field than non-Lyalpha emitters.

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Reshaping the labyrinth: the impact of galaxy mergers on Lyman radiation escape

Abstract: Galaxy mergers are transformational processes in the galaxy evolution. They have long been known to strongly impact the properties of galaxies, such as their morphologies and star formation. Mergers have been hypothesized to facilitate the escape of LyC and Lyman-alpha emission from galaxies for over a decade, and an increasing number of studies have looked at the question over the past few years. Nevertheless, many unknowns remain on the merger interaction configurations and timescales that promote Lyman radiation escape, and whether these processes could play a role during the Epoch of Reionization. The Lyman alpha and Continuum Origins Survey is a cycle 30 HST program investigating the global and resolved galaxy properties connected with Lyman Continuum emission in the low-redshift Universe. With deep imaging of 42 galaxies observed in Lyman Continuum at z~0.3, covering five bands in the rest-frame UV and optical, this survey provides the best sample to-date to identify galaxy mergers in a sample of LyC-emitting objects. Additionally, the Cosmic Disco citizen science project is providing detailed merger classifications for over 7000 galaxies with high-quality spectra from SDSS and DESI imaging. Here, I will present results using the classifications from those two surveys, shedding light on the specifics of the role of galaxy mergers into Lyman Continuum emission and escape from galaxies.

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Investigating the link between Lyman-α and 21cm HI emission in nearby galaxies

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Abstract: Lyman-alpha (Lyα, λ=1216 Å) emission serves as a crucial probe of galaxies across cosmic epochs, from the nearby Universe to the Epoch of Reionization. It has been proposed at a tracer of the neutral CGM, but despite its significance, the connection between Lyα emission and galaxy/CGM properties is not well calibrated. Here, we investigate the link between global Lyα emission and neutral hydrogen (HI) properties in nearby star-forming galaxies, leveraging multi-wavelength observations from the Lyman Alpha Reference Samples ((e)LARS). To do so, we compare 21cm HI observations obtained with the Karl G. Jansky Very Large Array (VLA) in D-array configuration (~38 kpc resolution) with Lyα properties derived from Hubble Space Telescope (HST) imaging and spectroscopy for 37 low-redshift (z~0.03) star-forming galaxies part of the (e)LARS sample.

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Tracing HI distribution and ionizing photon escape in star-forming galaxies across cosmic time

Abstract: Lyman alpha (Lya) is now widely used to trace and characterize the HI distribution in star-forming galaxies, notably through integral field spectroscopy (IFU). Probing the spatial configuration of HI in and around galaxies indeed provides important insight into gas flows, which are essential for understanding galaxy growth and evolution. Additionally, it helps to determine how ionizing radiation (Lyman continuum, LyC) propagates through the HI structures in the ISM and CGM before reaching our telescopes. This is particularly important for assessing how ionizing photons escape from galaxies into the IGM, helping to constrain the elusive sources of cosmic reionization. In this talk, I will first review what Lya emission reveals about the gas environment around high-redshift star-forming galaxies. I will then present recent work that connects gas properties and distribution, as traced by both Lya (HST/COS) and other nebular lines (Mg II and [O II] maps from IFUs), with the escape of ionizing photons in a statistical sample of confirmed LyC emitters (the LzLCS sample).

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The properties of Lyman Continnum candidates through combined spectroscopic and imaging observations

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Abstract: Identifying Lyman continuum (LyC) leakers at intermediate redshifts is crucial for understanding the properties of cosmic reionizers, as the opacity of the intergalactic medium (IGM) prevents direct detection of LyC emission from sources during the Epoch of Reionization (EoR). This talk will first present the discovery of new LyC leakers at z~2-3 identified using deep UV images. The LyC emission can be detected using HST/WFC3/F275W and F336W, as well as U-band of the ground-based telescope. These LyC leakers appear faint, exhibit blue UV continuum slopes, and have low masses. Combining the spectroscopic and imaging observations, we also explore the possible indirect indicators (like Lyman alpha, O32 ratio, and M_star, etc) and find clues between these properties and the LyC escaping. Then, we will talk about the physical properties of all known LyC leaker at z~2-3 using SED modeling and investigate their morphologies using high-resolution images from JWST. In the end, we also compare the high redshift LyC leakers with low redshift counterparts to understand the similarities and differences of the LyC escape mechanisms across cosmic time.

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The ionizing photon production efficiency of star-forming galaxies at z∼4-10

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Abstract: Investigating the ionizing emission of star-forming galaxies is critical to understanding their contribution to reionization and their impact on the surrounding environment. The number of ionizing photons available to reionize the intergalactic medium (IGM) depends not only on the abundance of galaxies but also on their efficiency in producing ionizing photons (ξion). In this work, we estimated the ξion in a sample of 731 galaxies at $4 \leq z \leq 10$ selected from different JWST spectroscopic surveys (CEERS, JADES, GLASS and GO-3073). We used the available HST and JWST photometry to perform a spectral energy distribution (SED) fitting to determine their physical properties and relate them with ξion. We used the BAGPIPES code for the SED fitting and assumed a delayed exponential model for the star formation history. We used the NIRSpec spectra from prism or grating configurations to estimate Balmer luminosities (Hα or Hβ) and then constrained ξion values after dust correction. We find a mild increase of the ionizing photon production efficiency with increasing redshift which is consistent with the evolution observed previously down to z~2. We find that faint low-mass galaxies with high levels of sSFRs present the best conditions for an efficient production of ionizing photons, while the low metallicity seems to play a more marginal role in setting such conditions, given the shallow trend found.

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Local Extreme Emission Line Galaxies in wide narrow band surveys: gateways to the early Universe

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Abstract: Extreme emission line galaxies (EELGs) are common in the early Universe, where their Lyman continuum radiation contribute significantly to reionization. However, their faintness makes it challenging to characterize their physical properties. EELGs at lower redshifts offer unique insights into Lyman photon escape physics and serve as analogs of the highest-redshift galaxies. We used the J-PLUS survey, covering 3000 deg^2 of the northern sky with 12 narrow/broadband filters, to identify over 1500 EELGs at z035 These galaxies were selected by flux excess in narrowband filters, indicative of large equivalent widths (>300 Å) in either [OIII]5007 or Hα, with ~90% purity and completeness. This approach avoids broadband color selection biases, achieving 20–50 times higher detection efficiency while also reaching fainter objects than spectroscopic surveys. Spectroscopic follow-up on 50 J-PLUS candidates, supplemented by ancillary data, confirmed their EELG nature, enabling the study of their physical properties through faint emission lines: metallicity, electron density, ionization parameter, and ionizing continuum slope. We find remarkable similarities between low-z EELGs and JWST-detected galaxies at z>6, particularly in the mass-metallicity diagram. These results and ongoing follow-up (including Chandra and HST observations) will enhance the understanding of EELGs, offering insights into the formation of the first galaxies and the state of their interstellar medium.

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Wolf-Rayet Galaxies as LyC Leakers: Identifying Candidates among Star-Forming Dwarf Galaxies

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Abstract: Star-forming dwarf galaxies, especially Wolf-Rayet (WR) dwarf galaxies, serve as a good proxy for galaxies formed in the early universe, due to their observed low metallicities, star formation rates and masses. Analysing these objects therefore will give us new insights into the evolution of galaxies. We selected emission line galaxies with a He II 4686 signature. With this selection, 699 objects from the SDSS DR18 remained, of which 17.8% appear as star-forming galaxies (SFGs), while the others show AGN signatures. 42 objects of the sample can be referred to as extreme metal poor galaxies (EMPGs) with metallicities between 6.99 log(O/H)+12 7.69. With further analysis for extreme emission line galaxies (EELGs) using the WR bump, to select WR galaxies, we found that almost all of these WR galaxy candidates could be identified as LyC leaker candidates. This corresponds to 20.8% of the detected SFGs.

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Lyman Continuum escape at cosmic noon: from typical galaxies to the most extreme starbursts

Abstract: The escape of ionizing Lyman continuum (LyC) photons from galaxies is a fundamental process that shaped cosmic reionization, yet its underlying mechanisms and dependence on galaxy properties remain poorly understood. In the first part of my talk, I will present the recently completed LyC22 survey, the most comprehensive JWST study of LyC-emitting sources at z~3. I will outline the key science goals of LyC22 and showcase ultra-deep JWST/NIRSpec spectra of high-redshift LyC emitters and non-emitters, covering essential emission lines from Mg II to [S II]. In the second part, I will present recent LyC observations of a rare population of extremely UV-bright starbursts at z~2–4. I will highlight some unique properties observed in these sources, including complex Lyman-alpha profiles and morphologies, resolved LyC emission, and extreme stellar populations.

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A (not so) Complete Unknown: multiple predictors of Lyman Continuum escape in the early Universe

Abstract: Despite significant progress in our understanding of the early Universe, the nature of the cosmic reionizers remains elusive. One of the most challenging parameters to determine is their Lyman Continuum (LyC) escape fraction (fesc), since direct observations during reionization are not feasible due to the absorption and scattering by the neutral gas in the IGM. In my talk, I will discuss how we can infer fesc for early galaxies by leveraging correlations between various galaxy properties and fesc. These correlations are calibrated at lower redshifts, where we have statistical samples of LyC emitting sources (LCEs). I will review the most widely used predictors for LyC leakage and assess their strengths and limitations when applied to high-redshift galaxies. I will also present the latest results from high-redshift galaxy surveys conducted with the JWST. These new observations not only offer insights into the ionizing emissivity of these sources but also provide a critical test for the predictors developed at lower redshifts, refining for example our understanding of the physical mechanisms that facilitate the escape of ionizing photons. Finally, I will discuss future prospects for this field, highlighting how upcoming observational campaigns may further bridge the gap between indirect diagnostics and the elusive properties of cosmic reionizers.

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Breaking the Mold: Dusty Giants as Lyman Continuum Leaking Sources in the Cosmic Noon

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Abstract: The escape of ionizing photons is a critical yet challenging problem in understanding the epoch of reionization (EoR). Current constraints on ionizing photon escape from star-forming galaxies are primarily derived from low-redshift studies (e.g., Flury et al. 2022). These investigations suggest that low-mass, compact, and dust-free star-forming galaxies are the most likely candidates for Lyman-continuum (LyC) photon leakage. Additionally, spectroscopic diagnostics, such as high [O III]/[O II] line ratios, are indicative of potential LyC escape, although they may represent necessary rather than sufficient conditions. I will present an analysis on an intriguing set of LyC leakers detected with AstroSat UVIT (Maulick+2024a,b) at redshifts of nearly 1, which exhibit moderate to high escape fractions despite their large stellar masses, significant dust content, and low O32 ratios. High-resolution HST and JWST imaging reveal that some of these objects show signs of mergers or disturbances. While studies (e.g., Wang et al. 2019 and Roy et al. 2024) have identified LyC leakers with similar properties, I will highlight key differences and discuss efforts to better understand these objects. Using NIRCam and HST grism data, MUSE observations, and UVIT LyC detections, I will explore the potential LyC leakage mechanisms from these systems.

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Probing Ionizing Photon Escape: ISM Absorption Lines and Dust Attenuation in SPHINX20

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Abstract: In this work we add new data to the public release of the SPHINX20 cosmological simulation and explore how well different methods predict the escape fraction of ionizing photons, helping to connect simulations with observations. The escape fraction of ionizing photons is a key quantity for understanding cosmic reionization, but predicting it accurately remains a challenge. This study expands the SPHINX20 public data by including interstellar medium (ISM) absorption lines, focusing on Si II 1260&1526 A. We use the public radiative transfer code RASCAS to simulate the lines, including multiple scattering, interaction with dust grains and absorption from the fine-structure level of Si+. These lines provide valuable information about the coverage of neutral gas in front of bright stars, and thus they are related to the escape of ionizing photons. We show that multiplying the residual flux of ISM absorption lines with the UV dust attenuation factor gives a reliable way to estimate the escape fraction. This simple method links observable properties to photon escape in a clear and consistent way. To test how well observational methods can predict the dust attenuation factor of our simulated galaxies, we used SED fitting tools (CIGALE and LePhare) and spectral fitting with FiCUS. While the fits increase the uncertainty of the escape fractions, they produce reasonable results, showing that the method can be applied to real observations.

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Efficient LyC leakage due to radiation-driven outflows in compact bursts

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Abstract: The escape of LyC photons emitted by massive stars from the dense interstellar medium of galaxies is one of the most significant bottlenecks for cosmological reionization. The escape fraction shows significant scatter between galaxies, and anisotropic, spatial variation within them, motivating further study of the underlying physical factors responsible for these trends. Observations from JWST of lensed fields have revealed that young star clusters in galaxies at cosmic dawn are systematically more compact and dense compared to those in weakly star-forming galaxies in the local Universe. In this talk, I will present insights from cutting-edge radiation hydrodynamical simulations of star cluster formation, focusing on how LyC escape systematically varies with cloud and clump properties. I will show that dense, compact bursts of efficient star formation are prolific sites of rapid, localized LyC leakage, driven by radiation pressure on dust grains, well before the death of massive LyC-producing stars. Additionally, I will discuss the observational implications of this framework, show that it is consistent with the literature, and discuss the significance for LyC escape from galaxies and cosmic reionization.

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A resolved Lyman-Alpha profile with doubly peaked emission at z∼7

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Abstract: The epoch of reionization is a landmark in structure formation and galaxy evolution. How it happened is still not clear, especially regarding which population of objects was responsible for contributing the bulk of ionizing photons toward this process. Doubly-peaked Lyman-Alpha profiles in this epoch are of particular interest since they hold information about the escape of ionizing radiation and the environment surrounding the source. We wish to understand the escape mechanisms of ionizing radiation in Lyman-Alpha emitters during this time and the origin of a doubly-peaked Lyman-alpha profile as well as estimating the size of a potential ionized bubble. Using radiative transfer models, we fit the line profile of a bright Lyman-Alpha emitter at z∼6.9 using various gas geometries. The line modeling reveals significant radiation escape from this system. While the studied source reveals significant escape (fesc(LyA) ∼0.8 as predicted by the best fitting radiative transfer model) and appears to inhabit an ionized bubble. Radiative transfer modeling predicts the line to be completely redwards of the systemic redshift. We suggest the line morphology is produced by inflows, multiple components emitting Lyα, or by an absorbing component in the red wing. We propose that CDFS-1's profile holds two red peaks produced by winds within the system. Its high fesc(Lya) and the low-velocity offset from the systemic redshift suggest that the source is an acive ionizing agent.

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Probing galaxy kinematics and the epoch of reionization using Lyman-alpha emission

Abstract: Hydrogen Lyman-alpha (Lyα) emission serves as a vital tool for studying the high-redshift Universe. Determining the timing of reionization and identifying sources capable of emitting sufficient ionizing photons (Lyman-continuum or LyC photons) remain key open questions in astrophysics. Direct detection of LyC photons beyond $z>4$ is nearly impossible due to strong attenuation by the neutral intergalactic medium (IGM). Lyα emission serves as a reliable indirect indicator of LyC leakage. The emergent Lyα spectra, characterized by single, double or multiple-peaked profiles, provide valuable insights into the kinematics of the circumgalactic medium (CGM) and the structure of the interstellar medium (ISM) of Lyα-emitting galaxies, or Lyα emitters (LAEs). Using data from VLT/MUSE, we have been conducting spatially-resolved studies of LAEs up to the edge of cosmic reionization epoch. By modeling observed single and double-peaked Lyα profiles with radiative transfer simulations, we investigate the complex gas kinematics, including inflows and outflows, as well as ISM properties and conditions that facilitate the escape of both Lyα and LyC photons. We also explore the survival of Lyα photons in luminous LAEs exhibiting broad Lyα line profiles during the reionization era. Our findings reveal that high-luminosity LAEs at $z>6$ are more likely to reside in highly ionized regions, reducing the impact of IGM scattering. This work contributes to a deeper understanding of cosmic reionization.

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Inferring the position and size of individual HII regions using Lyman-alpha observations with JWST

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Abstract: The Lyman-α line is a sensitive probe of the neutral hydrogen along the line-of-sight of a galaxy and can thus be used to constrain the topology of the Epoch of Reionization (EoR). Probing the topology is important to connect the sources that reionized the Universe to the growth of cosmic HII regions. The usual approaches include a number of simplifying assumptions including treating galaxies as independent probes of their environments. In this work we present a new framework to infer the properties of the local HII region around a group of galaxies. We forward-model Lyman-alpha spectra as would be observed by JWST, dealing with all relevant sources of uncertainty, including the uncertainty in the intrinsic emission and surrounding EoR topology. We take into account each galaxy's relative location with respect to the local HII region, using the full potential of the Lyman-α line. We find that the observed galaxy number densities of $n_{\rm gal} \sim 0.0025-0.00375$ cMpc^{-3} should suffice to estimate the size and location of the local HII region at a percent level accuracy. Such number densities are well within reach of future JWST surveys.

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The massive star population of IZw18

Abstract: I will present new results of the resolved star population in IZw18, based on infrared JWST imaging, and new HST imaging in the UV/blue and narrowband imaging targeting HeII.

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LyC detections at high redshift: precise escape fractions for individual leakers?

Abstract: It is crucial to consider models of reionization in the context of f_esc analyses at cosmic noon, considering direct f_esc measurements in the epoch of reionization remain impossible even with the observational capabilities of JWST. I will summarize our recent findings examining f_esc as a function of galaxy properties at z~3 within the Keck Lyman Continuum Spectroscopic survey (KLCS), focusing on the connection between f_esc and the shape of the Lyman alpha profile. While a strong correlation has been demonstrated at low (z~0.3) redshift, this connection remains untested at high redshift. I will present our analysis of f_esc and Lyman alpha profile shape within the KLCS dataset, highlighting the apparent evolution of these trends compared to those observed at z~0.3. With the importance of high-redshift LyC surveys established, I will present a novel method to place more precise constraints on escape fractions of individual high-redshift objects considering the significant sightline-to-sightline variation of the IGM attenuation on the LyC region. This statistical method utilizes measurements of large scale structure via Lya tomography of the LATIS survey in conjunction with the cosmological simulation ASTRID to reduce this critical uncertainty.

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Cutting through the Clouds: Comparing Indirect Tracers of Ionizing Photon Escape

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Abstract: Rest-frame far-ultraviolet (FUV) observations from JWST are currently revolutionizing our understanding of the high-z galaxies that drove reionization and the mechanisms by which they accomplished it. Although we know that the fraction of metals in neutral and low-ionization states trace the neutral gas in and around these galaxies, the low S/N and resolution of their absorption at high redshifts limits both the interpretation of these lines and properties that can be derived from them. With the 45 nearby star-forming galaxies from the CLASSY survey, I investigate how interstellar absorption line measurements from a series of neutral and low-ionization metals (O I, Si II, S II, C II, Al II) relate to indirect predictors of ionizing photon escape and global characteristics of their host galaxies. The high-S/N and high-resolution of these FUV spectra allow for detailed study of how these properties are related, which can be used to predict the neutral gas properties and ionizing photon escape of galaxies at higher redshifts.

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Extended Lyman-α emission in quasar environments at z > 2 detected with J-PAS narrow-band imaging

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Abstract: Lyα emission serves as a key tracer of the circumgalactic medium (CGM) at high redshifts, offering valuable insights into galaxy formation and evolution in the early Universe while acting as an indicator of overdense regions and large-scale structures. In this talk, I will present a study of extended Lyα emission around quasars at $z > 2$, revealed through narrow-band imaging in the early data release of J-PAS, a survey that covers the optical range using 56 narrow-band filters. The discovered nebula includes an extended Lyα emitter (LAE) adjacent to a quasar with Lyα emission at the same redshift, as measured in the J-PAS photospectra. The discussion will explore possible origins of this extended emission, including quasar-driven photoionization, galaxy outflows, and interactions with nearby LAEs. These findings provide insights into quasar feedback processes, CGM dynamics, and their broader role in galaxy evolution. Our results showcase J-PAS's unique ability to detect faint, extended structures through multi-band photometry. The survey's comprehensive wide-field coverage and contiguous narrow-band filters effectively provide a low-resolution, wide-area integral field unit (IFU) view of the northern sky, offering new perspectives on the dynamic relationship between quasars and their environments at high redshift.

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Tracing Ionizing Continuum Slopes and Excitation Bimodality in AGN through Mid-IR Diagnostics

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Abstract: The softness diagram, when combined with large grids of photoionization models and interpreted using Bayesian-like codes such as HII-CHI-nistry, constitutes a robust tool to study the ionizing radiation field and the fraction of escaping photons in galaxies. Here, we extend this approach to explore its applicability in the narrow-line regions (NLR) of active galactic nuclei (AGN). We adapt the softness diagram to include high-excitation IR lines, such as [Ne V] 14.3, 24.3 µm and [O IV] 25.9 µm, providing robust diagnostics for the shape of the ionizing continuum. Using the Bayesian-based HCm-Teff-IR code, we derive the ionizing continuum slope (α_OX) and ionization parameter (U) from combinations of emission-line ratios, including ([Ne II] + [Ne III])/[Ne V] and [O III]/[O IV]. This method is applied to a large AGN sample with mid-IR spectroscopic data from Spitzer/IRS, Herschel/PACS, and SOFIA/FIFI-LS. Our results reveal two distinct AGN populations: one with a harder ionizing continuum ($\alpha\_OX \approx -1.4$) and low log U (≈ -2.4), associated with low-luminosity AGN where the accretion disk is expected to recede; and another with a softer continuum ($\alpha\_OX \approx -1.7$) and high log U (≈ -1.5), linked to radiatively efficient AGN such as bright Seyfert nuclei. We interpret this anti-correlated bimodality as a consequence of changes in the surrounding gas geometry, likely driven by reduced absorption of high-energy ionizing photons during phases of decreased accretion disk efficiency.

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What Shapes the Distribution of Lyman Alpha Halos?

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Abstract: Observed Lyman alpha emitters (LAEs) exhibit a wide diversity of spatial halo shapes and spectral profiles, but these represent only the detectable fraction of the total LAE population. The factors favoring/disfavoring detection of a given LAE include its intrinsic luminosity, the available physical pathways for Lyman alpha (Lya) emission to escape the host galaxy's CGM, and the halo-dependent flux limitations of the observing survey. We model ranges of Lya halo (LAH) emission in spatial and spectral components, and by placing model LAHs in VLT/MUSE observations, we study the detectability impact of these factors. We construct halo-dependent selection functions for 3 z 5 LAHs, allowing us to uncover the intrinsic distributions of the spectral line width, halo scale length (rsH), and halo flux fraction (fH). Then we apply our selection function to spectra of a mock Lya population based on a simulated LAE, identifying host galaxy properties such as star formation and gas phase that yield more/less detectable LAH shapes. Finally, we explore available data from JWST to relate host galaxy characteristics to halo distributions and Lya escape.

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UV/Lya Attenuation and the Effect of Gas Covering Fraction on the Emergent Lya Emission of High-Redshift Galaxies

Abstract: In this review talk, I will present an introduction to stellar dust attenuation curves, summarize a few key empirical constraints on the shape of the curve in high-redshift galaxies, and discuss how the curve varies with galaxy properties. I will also present a new analysis of the shape of the nebular dust attenuation curve and novel constraints on dust covering fractions from JWST/NIRSpec spectroscopy of Balmer and Paschen emission lines. Finally, I will discuss the relative importance of stellar populations, dust, and gas covering fraction in modulating the emergent Lya emission in high-redshift galaxies.

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The Ly-α nebulas around quasars as evidence of the effect of AGN outflows on the CGM

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Abstract: The effect of the black hole activity on its host galaxy has been the focus of multiple studies in the past decades. In particular, the so-called AGN feedback may have a multi-scale effect on the physical properties of surrounding gas, spanning from the Interstellar Medium (ISM) to the Circum-galactic Medium (CGM). By using a set of cosmological, radiation- hydrodynamic simulations to study the AGN-driven outflows and the Ly-α nebulae around high redshift quasars, Costa et al. (2022) predicts that such outflows facilitate the escape of Ly-α photons from the galactic nucleus by decreasing the HI and dust optical depths in the host galaxy. I will present our observational test of the theoretical prediction by Costa et al. (2022): using ERIS/VLT, we follow up on a sample of quasars at z~2-3, which were previously observed with MUSE/VLT and KCWI/Keck to be surrounded by Ly-α nebulae. By tracing the forbidden [OIII]λ5007 emission line, our observations allow us to study the kinematics of the ionized component of the AGN-driven outflows at ISM scales. I will show how the properties of these outflows detected from our observations correlate with the size and morphology of the previously characterized Ly-α nebulae. Finally, I will discuss the implications of our findings on the models (e.g. Costa et al. 2022) and draw a general picture of the impact of AGN-driven outflows at CGM-scales.

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The roles of radiative and mechanical feedback and interaction from NIRSpec IFU observations

Abstract: The radiative transfer and escape of Lyman-continuum photons from star-forming galaxies has long been acknowledged as an inherently multi-scale problem. To properly trace the escape paths of these photons, it is necessary to not only be able to pinpont the points of escape with high accuracy, but also to study ISM properties such as ionization, kinematics and geometry on physical scales down to individual H II regions. Spatially detailed study of LyC is however extremely challenging, owing to atmospheric and Galactic absorption and the technical difficulty of observing in the extreme UV.

The Sunburst Arc is a gravitationally lensed, highly magnified, strong Lyman-continuum emitting galaxy at z = 2.4. It is currently the only known galaxy, for which it is possible to study both Lyman-continuum and optical emission lines in sufficient detail to disentangle the questions of e.g. geometry, ionization and mechanical vs. radiative feedback. In this talk, I will present results of a Cycle 1 JWST program observing the ISM of this galaxy in high detail in the rest-optical using the NIRSpec IFU. I will discuss both detailed maps of kinematics and ionization properties, tests of observational indicators of Lyman-continuum escape, and global properties of the galaxy seen in the context of other Lyman-continuum leakers at Cosmic Noon and beyond.

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Key results from the AstroSat UV Deep Field

Abstract: The ultraviolet Imaging Telescope on AstroSat has been used to create one of the deepest UV images of the GOODS South and North field in two passbands spanning a wavelength range from 130 - 300 nm. The resulting AstroSat UV Deep Field (AUDF), with a depth of ~27 AB mag and PSF ~1.2", has been successful in identifying more than a dozen Lyman continuum leakers in the redshift range z~1 - 2 and thereby bridging a gap between the low-z and high-z leakers. At these redshifts, AUDF probes Lyman continuum photons at rest-frame ~600 angstroms, opening a new window to probe the ionizing spectrum of leaky galaxies. Furthermore, AUDF South has been excellent in detecting extended UV emission beyond the optical boundary of star-forming galaxies at z>0.2.

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Unveiling the ionising properties of galaxies at the Epoch of Reionisation with JWST NIRCam

Author: Charlotte Simmonds
Co-authors: The JADES collaboration

Abstract: The Epoch of Reionisation describes the cosmic period in which the Universe went from being dark and neutral, to being transparent to radiation. Understanding the first galaxies responsible for lighting up the Universe is of utmost importance for unveiling the mysteries of this epoch.

In this talk I will present work done through the use of deep NIRCam imaging from the JWST Advanced Deep Extragalactic Survey (JADES) to study the evolution of the ionising photon production efficiency, ξ_{ion}, with redshift ($3<z<9$). When observing Lyman-alpha emitters (LAEs) and emission-line galaxies (ELGs), we find that low-mass galaxies with bursty star formation histories (SFHs) are more efficient in producing ionising radiation, and could represent the main drivers of reionisation. However, we find that the observed increase of ξ_{ion} with redshift depends on the nature of the sample: the trends observed in LAEs and ELGs are less significant when a stellar-mass complete sample is used instead.

By combining these results we find that galaxies are likely the main drivers of reionisation, and that there is no crisis in the cosmic ionising budget when a stellar-mass complete sample is considered. I will conclude by presenting preliminary results regarding the star-forming main sequence of galaxies and its connection to bursty SFHs.

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Are Lyman-Alpha Halos different beyond z=6?

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Abstract: We present a comparative study of Lyman-alpha (Lyα) Halos at z~3 and z>6 to assess their evolution towards the end of reionization. We use MUSE data of very different depths to attain similar detection limits across both low and high redshift samples. We distinguish between objects with and without extended Lyα emission and fit two-component GALFIT models to Lyα halos where extended emission is detected. By comparing the prominence and properties of such halos at z~3.5, long after reionization ended, and z>6, at the tail of the reionization epoch, we trace how the circumgalactic medium (CGM) reacts to the changes in the surrounding intergalactic medium and its ionisation state. We show that, after accounting for the detection limit, Lyα halos at z>6 are significantly more compact than their counterparts at z∼3. Our results provide new constraints for theoretical studies of Lyα emission at the conclusion of cosmic reionization.

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Uncertainties in Population and Spectral Synthesis

Abstract: The interpretation of a galaxy's ionizing photon production across a broad range of redshifts and environments depends ultimately on our ability to model stellar populations. Either observations are directly compared to models to obtain the best fitting galaxy properties, or the observations are interpreted as implying physical conditions on the basis of scaling relations which are themselves model calibrated. Evidence suggests that the young, low metallicity stellar populations observed in the more distant Universe, and which give rise to the progenitors of gravitational wave or other transient sources, are distinctly different from those observed locally. In particular, the impact of parameters such as stellar multiplicity or rotation on the evolution of stellar populations cannot be ignored in these regimes. In this talk I will consider the current state of the art of population and spectral synthesis models, comment on where they perform well and the areas in which further improvements are called for.

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Probing Lyman Continuum Escape: Bayesian SED Modeling of Low-Redshift Analogues for High-Redshift Galaxies

Abstract: Lyman Continuum (LyC) escape is a fundamental parameter for understanding the evolution of galaxies and the intergalactic medium (IGM). To shed light on the connection between LyC escape, stellar population properties, and morphology, we investigate the escape fraction ($f$esc) of LyC photons. Direct observation of LyC at the Epoch of Reionisation ($z \gtrsim 6$) is impeded by absorption, necessitating indirect methods for inference. To test these methods, we examine low-redshift galaxies whose properties serve as suitable analogues for the high-redshift galaxies of interest. We utilise our Bayesian spectral energy distribution (SED) fitting code, PROSPECTOR, which incorporates a flexible star formation history, variable dust attenuation, a self-consistent model of nebular emission, and accounts for slit-loss effects. This enables simultaneous fitting of emission line fluxes and broadband photometry.

We analyse 66 known LyC emitters from the Low-redshift Lyman Continuum Survey (LzLCS) within multiple distinct modeling frameworks, exploring the influence of different priors of star formation histories and $f$esc as well as the inclusion and exclusion of slit-loss effects. We compare our results with those obtained through equivalent widths of nebular emission lines, emission line flux ratios, Lyα emission line profiles, SFR surface density, and UV continuum slope and magnitude. We discuss the various degeneracies affecting escape fraction estimations and critically evaluate the widely accepted results and methodologies used to infer escape fractions at high redshift.

Building on these results, we establish a stable modeling framework, which we apply to a mass-complete NIRSpec sample of galaxies at the Epoch of Reionisation.

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Cosmic Change Agents: Studying Massive Stars at Cosmic Noon

Abstract: The intersection of galaxy evolution and stellar astrophysics has emerged as one of the most dynamic frontiers in contemporary astronomy. Massive stars, in particular, have a profound impact on galaxies: they are not only responsible for nearly all of the light we observe from star-forming systems (from rest-frame ultraviolet to infrared wavelengths), but they are also an important source of energetic feedback (in the form of radiation pressure, stellar winds, and supernovae) that regulates future star formation. In recent years, our team has played a pivotal role in establishing the ubiquity of alpha-enhanced ([O/Fe]~0.4), metal-poor ([Fe/H]~-0.7) stellar populations in nascent galaxies at high redshift. In my talk, I will share the latest findings from CECILIA, a Cycle 1 JWST/NIRSpec program that has obtained some of the deepest rest-optical spectra of individual $z>2$ galaxies to date. These observations enable the measurement of myriad spectral features that are sensitive to the properties of the ionized gas and massive stars in the galaxies. Specifically, I will demonstrate how the combination of JWST observations and new rest-UV spectra of the same galaxies allows us to characterize their massive stars in detail. These unique data provide novel constraints on the shape of the massive stars' ionizing spectra and facilitate direct comparisons with predictions from stellar population synthesis models. To conclude, I will highlight areas where we need new and improved stellar models to interpret observations of high-z galaxies, as well as opportunities to use current and future galaxy studies to provide direct constraints on the chemically distinct massive stars that are commonplace at early times.

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Unveiling the cosmic web through Lyα emission: an ultra-deep observation with MUSE

Abstract: The existence of filaments connecting galaxies, within which galaxies form, has long been predicted by structure formation theories in a cold dark matter-dominated Universe. However, direct imaging of these filaments in emission has remained elusive until the advent of large-format integral field spectrographs like the Multi Unit Spectroscopic Explorer (MUSE) at the Very Large Telescope. In this talk, I will present new direct detections of cosmic web filaments revealed in Lyα emission from an ultra-deep (142-hour) observation in the MUSE Ultra Deep Field. This groundbreaking dataset allows us to directly study the physical properties of two extended emitting structures, including morphology, surface brightness profiles, and the transition radius between the circumgalactic and intergalactic medium. These filaments span scales from 3 cMpc to 5 cMpc and are observed both between two massive cosmic web nodes (a pair of bright quasars at redshift z~3.22) and within a rich overdensity of Lyα emitters at redshift z~4. I will compare these observations to numerical simulations and discuss the Lyα emission mechanisms contributing to the observed signal. These discoveries represent a significant step forward in the study of large-scale structures in emission, offering a powerful new approach to tracing dark matter distribution and gas dynamics within the cosmic web, while also providing a testbed for models of complex Lyα emission.

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Probing Cosmic Reionization with JWST & Subaru: Lyα Damping Wing and Insights on LyC Leakers

Abstract: We present new measurements of Lyman α damping wing absorption in over 500 galaxy spectra at 5 z 13 from JWST NIRSpec data (ERS, DDT, GO, GTO), greatly expanding on previous samples of ~30 galaxies. This large dataset enables a precise analysis of Lyα damping wings, accounting for UV magnitudes, UV slopes, and potential nebular contamination. We infer the neutral hydrogen fraction (x_HI) using semi-numerical and analytical IGM attenuation models, combined with intrinsic galaxy spectra from advanced fitting codes and newly developed galaxy-spectrum templates. This comprehensive approach tightens constraints on the global IGM neutral fraction derived from Lyα damping wings as well the size measurement of ionizing bubble around galaxies. By integrating JWST-based results with Subaru/Hyper Suprime-Cam LAE surveys, we map the neutral fraction's evolution through cosmic reionization, revealing its rapid progression and the properties of ionizing sources responsible for cosmic reionization. Building on these findings, we propose strategic JWST observations to refine galaxy damping wing studies. We also outline upcoming spectroscopy of ~10,000 z > 5 Lyα emitters with Subaru's Prime Focus Spectrograph, emphasizing its unique role in statistically uncovering the progress of reionization and the properties of LAEs to understand what is responsible for LyC leakage at the EoR.

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Bayesian Component Separation for DESI LAE Automated Spectroscopic Redshifts & Photometric Targeting

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Abstract: Lyman Alpha Emitters (LAEs) are valuable high-redshift cosmological probes traditionally targeted with specialized narrow-band photometric surveys. In ground-based spectroscopy, it can be difficult to distinguish the sharp LAE peak from residual sky emission lines, leading to misclassified redshifts. We present a Bayesian spectral component separation technique to automatically determine spectroscopic redshifts for LAEs while marginalizing over sky residuals. We use visually inspected DESI LAE targets to create a data-driven prior and can determine redshift by jointly inferring sky residual, LAE, and residual components for each individual spectrum. We demonstrate this method on 910 photometrically targeted $z = 2\text{-}4$ DESI LAE candidate spectra and determine their redshifts with >90% accuracy compared to visually inspected redshifts. Using the chi-squared value from our pipeline as a proxy for detection confidence, we then explore potential survey design choices and implications for targeting LAEs with medium-band photometry. This method allows for scalability and accuracy in determining spectroscopic redshifts in DESI and the results provide recommendations for LAE targeting in anticipation of future high-redshift spectroscopic surveys, such as DESI-2. I will also discuss a new wide-field intermediate-band imaging survey (IBIS) designed to select high-redshift LAE and LBG targets for the DESI-2 survey.

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Star Clusters as Key Agents of Cosmic Hydrogen Reionization

Abstract: Gravitational lensing, serving as a cosmic telescope, provides access to physical scales and luminosities in the distant Universe with unprecedented accuracy and depth. The combined capabilities of the Hubble Space Telescope (HST) and the James Webb Space Telescope (JWST), together with gravitational lensing, have pushed astronomical observations to scales of a few tens of parsecs, while Extremely Large Telescope (ELT) imaging will routinely achieve parsec-scale resolution with modest magnification. In this talk, I will present insights from current studies on lensed and highly magnified high-redshift galaxies, leading to the identification of star-forming complexes, gravitationally bound star clusters, and the elusive proto-globulars -- potential key players in cosmic reionization.

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Photons under the rug: hiding the ionizing photon surplus in the Cosmic Infrared Background

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Abstract: The study of Munoz et al. 2024 recently highlighted a potential tension between JWST and Planck constraints on the reionization timeline: if we combine the UV luminosity function and the high ionizing efficiencies inferred from high-z JWST data with the significant escape fractions derived from the low-z Lyman continuum survey, the observed galaxies would drive an earlier reionization than expected from CMB measures. One possible out involves much lower escape fractions of blue galaxies than predicted by low-z studies. We examine whether very low escape fractions at high z – with most of the absorbed ionizing flux re-emitted as Lyα radiation – would conflict with observations of the Cosmic Infrared Background (CIB). In fact, Lyα emission at $7 \lesssim z \lesssim 15$ would be redshifted to $\lambda \simeq 1$–2 μm and contribute to the local CIB. The most recent CIB measures suggest an excess flux beyond resolved galaxy populations in the order of a few $nW/m^2/sr$, hinting towards an unresolved high-z component; further constraints by Euclid will help reduce the uncertainty associated with the measured discrepancy in the near future. We find that, even in the extreme scenario of maximal ionizing efficiency and zero escape fraction, the predicted Lyα flux from high-z, JWST galaxies would still lie at least two orders of magnitude below the CIB excess. This suggests the CIB could effectively "hide" the surplus ionizing photons, offering a plausible solution to the reionization timeline tension.

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Ionization and Galaxy Properties of Distant HeII Emitters from Multiwavelength Spectrophotometry

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Abstract: The ionization properties of distant star forming galaxies (SFG) and the relation with global galaxy properties have been studied. The detection of HeII recombination emission indicates the presence of very hard ionizing radiation (photon energy $\geqslant$ 54 eV), which is expected to be enhanced in low metallicity SFGs. Strong HeII emission can be produced by low-metallicity massive stellar populations, apparently more common in high-z SFGs. For these galaxies the presence of strong HeII lines in their spectra is suggested as a good tracer of candidate Population III stars, which should produce huge amounts of hard ionizing radiation and metal pollution, thus contributing significantly to the universe's reionization and chemical enrichment. Here we present the results of our study of the physical properties of a sample of 30 distant SFGs selected from the HUDFS as strong HeII 1640 Å emitters. Their optical and IR spectral lines have been measured which, together with available deep imaging and multi-wavelength photometry, are used to derive the spectral properties and main galaxy parameters from SED fit. Comparison of the derived spectral and physical properties and ionization budgets with predictions from photoionization models and our simulations of extreme low metallicity HeII emitters will be discussed.

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Observing Lyman radiation in the blue optical with BlueMUSE

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Lyman Continuum studies from space in the next decades

Abstract: First, I will summarize the uniquely complementary roles of Hubble and Webb from HST+JWST images of 414-500 hours of combined depth. My message is that HST provides the essential unobscured rest-frame UV-blue data for all objects below the peak in the cosmic SFH rate at z<2 (i.e., the last 10 billion years of cosmic history), while JWST has its unique near- and mid-IR advantage at z>3 (i.e., the first two billion years) and for obscured objects at all redshifts. Hence, HST must be kept alive for as long as possible (for details, see astro-ph/2410.01187v1). Next, I will make the case that high space-based resolution is needed for contamination free Lyman Continuum (LyC) work at z ~< 3.5, where the IGM is still transparent enough to do so, and that all direct UV-blue imaging or spectroscopy of redshifted LyC will be subject to ``natural confusion'', i.e., objects overlapping due to their own finite sizes at AB<31 mag. Hence, very faint foreground objects (at z < z_LyC) may contaminate the intended LyC signal, possibly at the 30% level.
Last, I will summarize the requirements for the Habitable World Observatory (HWO) to do reliable and long-lasting LyC work at z<3.5 in the decades after HWO's launch intended for the 2040's, highlighting lessons learned from the HST and JWST missions to make this HWO mission succeed and work well for decades.

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Merging Signatures in an Offset Lyman Continuum Emitter at Redshift 3.8

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Abstract: Lyman continuum (LyC) emitters at $z > 3$ provide critical samples for studying the contribution of galaxies to the ionizing background in the epoch of reionization. We collect a sample of $z > 3$ LyC emitters, a dominant fraction (∼60%–70%) of which show spatial offsets between LyC emission and the nonionizing continuum. From this sample, especially, we find a case of an offset LyC emitter, CDFS-6664 ($z = 3.797$), which shows two components in the high-resolution Hubble Space Telescope and James Webb Space Telescope images. The exceptionally rich data set of CDFS-6664 enables us to extract the two components across multiple wavelengths and estimate their physical properties. We show that CDFS-6664 is consistent with a major merger system with boosted star formation in both components and that the offset LyC emission is most likely associated with the bluer and younger component in this merging system. Our result offers an example in which the offset can be caused by a merger. Future observations of more offset LyC emitters would elucidate the role that mergers play in the escape of LyC photons.

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Discovery of a Lyα blob photo-ionised by a super-cluster of massive stars associated with a z = 3.49 galaxy

Abstract: We report the discovery and characterisation of a Lyman α (Lyα) blob close to a galaxy at redshift z = 3.49. We present the analysis we performed to check whether the companion galaxy could be the source of the ionised photons responsible for the Lyα emission from the blob. Methods. We used images obtained from the 10.4 m Gran Telescopio Canarias (GTC) telescope that are part of the Survey of High-z Absorption Red and Dead Sources (SHARDS) project. The blob is only visible in the F551W17 filter, centred around the Lyα line at the redshift of the galaxy. We measured the luminosity of the blob with a two-step procedure. Here, we start with a description of the radial surface-brightness (SB) profile of the galaxy, using a Sérsic function. We then removed this model from the SB profile of the blob and measured the luminosity of the blob alone. We also estimated the Lyα continuum of the galaxy using an Advanced Camera for Surveys (ACS) image from the Hubble Space Telescope (HST) in the F606W filter, which is wider than the SHARDS one and centred at about the same wavelength. In this image, the galaxy is visible, but the blob is not detected, since its Lyα emission is diluted in the larger wavelength range of the F606W filter. Results. We find that the Lyα luminosity of the blob is 1.0 × 1043 erg s-1, in agreement with other Lyα blobs reported in the literature. The luminosity of the galaxy in the same filter is 2.9 × 1042 erg s-1. The luminosity within the HST/ACS image that we used to estimate the Lyα continuum emission is Lcont = 1.1 × 1043 erg s-1. With these values, we have been able to estimate the Lyα equivalent width (EW), found to be 111 Å (rest-frame). This value is in good agreement with the literature and suggests that a super-cluster of massive (1 - 2 × 107 M⊙) and young (2 - 4 Myr) stars could be responsible for the ionisation of the blob. We also used two other methods to estimate the luminosity of the galaxy and the blob to assess the robustness of our results. We find a reasonable agreement that supports our conclusions. It is worth noting that the Lyα blob is spatially decoupled from the galaxy by 3 GTC/SHARDS pixels, corresponding to 5.7 kpc at the redshift of the objects. This misalignment could suggest the presence of an ionised cone of material escaping from the galaxy, as found in nearby galaxies such as M 82.

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Chemical Abundances Inform LyC Escape Conditions at z>5

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Abstract: Observations with JWST have opened a new window into the physical conditions, properties, and chemical abundance patterns of carbon, nitrogen, and oxygen in high-redshift galaxies. However, the unexpected significant N/O excess in early galaxies is difficult to explain with the standard nucleosynthesis driven by massive stars. Interestingly, Lyman Continuum Emitters (LCEs) share similar properties with high-redshift galaxies, such as ionization parameters and stellar mass, providing an excellent opportunity to investigate the unique conditions of Lyman continuum escape. We present an analysis of a local sample of ~ 50 LCEs (z ~ 0.3) with direct chemical abundances, in conjunction with a sample of several galaxies at z > 5. Our preliminary results show that LCEs display a similar range in metallicity to high-redshift galaxies, primarily due to the high-ionization radiation of these galaxies. Moreover, we find that LCEs have similar C/N abundances to high-redshift galaxies at z > 5. We explore the possible unique star formation histories or very massive stars necessary to explain C/N vs 12+(O/H) as possible unique conditions for Lyman continuum escape.

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Identifying candidates for low-metallicity Lyman radiation leakage in the DESI survey

Abstract: Understanding the mechanisms that facilitate the escape of Lyman photons is critical to constraining the role of star-forming galaxies in cosmic reionization. While low-metallicity galaxies are thought to be prime candidates for efficient Lyman continuum (LyC) photon leakage, identifying such systems at low redshift remains challenging. Using data from the DESI (Dark Energy Spectroscopic Instrument) survey, we conduct a systematic search for low-metallicity galaxies that likely are LyC leakers. We identified a sample of low-metallicity dwarf galaxies with high [O III]/[O II] ratios, suggesting reduced neutral hydrogen column densities and potential pathways for LyC photon escape. Here, we will present our sample and explore the physical properties of their interstellar medium and stellar components, as derived from optical spectroscopy.