
OAC, Crete
Escape of Lyman radiation from galactic labyrinths
2023

Review : 40 min
Keynote Presentation: 30 min
Contributed talk : 20 min

01) **Fabrice Martins** (Review)
Université de Montpellier, France (email: fabrice.martins@umontpellier.fr)

Lyman radiation production in massive stars

In this talk I will give an overview of the production of Lyman radiation in various types of massive stars. After showing the main stellar parameters that control the production and intensity of Lyman radiation, I will discuss the various sources that produce Lyman radiation: OB stars, WR stars, very and super-massive stars, stripped stars, stars evolving quasi-homogeneously.
I will also discuss the effect of metallicity on the Lyman radiation production.

02) **Andreas Sander** (Keynote Presentation)
ZAH, University of Heidelberg, Germany (email: andreas.sander@uni-heidelberg.de)

Do we know the start of the labyrinth? The challenge of determining ionizing fluxes from massive stars

Massive stars in young stellar clusters are the dominant source of Lyman photons on subgalacic scales. During most of their lifetime, massive stars show hot effective temperatures, thus emitting a significant number of photons with energies sufficiently high enough to ionize hydrogen and potentially also other elements. However, estimating the ionizing flux budget of hot stars is not trivial, as simple blackbody estimates can be off by orders of magnitude, especially when trying to determine the crucial ionizing flux above 54 eV that can give rise to the nebular He II emission observed in particular in low-metallicity galaxies.

To obtain a realistic picture of the labyrinth onset for Lyman photons, a proper modelling of the emergent spectral energy distributions (SEDs) of hot stars is required. Shaped by their chemical composition and their stellar winds, detailed stellar atmosphere models are required to achieve this task and get a theoretical insight on the resulting SEDs and ionizing fluxes. In this talk, I will give an overview of the ionizing impact of different types of massive stars. Starting with a brief introduction of the underlying model technique, the talk will show resulting SEDs and disucss the influence of abudances, metallicity, and stellar winds. A particular emphasis will be put on He II ionizing photons and the challenge to estimate them correctly in population synthesis models.

03) **Marta Lorenzo**
Centro de Astrobiología (CAB, CSIC-INTA) (email: mlorenzo@cab.inta-csic.es)
Co-authors: Miriam Garcia, Francisco Najarro and Miguel Cerviño

The Missing Piece in the Reionization: Quantifying the Ionizing Flux of Extremely Metal-poor Massive Stars

Extremely metal-poor massive stars are one of the prime suspects for the reionization of the Universe. However, their contribution to the ionizing photon budget of early galaxies is poorly constrained due to the paucity of comprehensive spectroscopic studies at metallicities lower than the Small Magellanic Cloud (SMC, 1/5 $Z_{\odot}$).

In this talk, we will present the first estimates of ionizing photon production rates calculated directly from the quantitative spectroscopic analysis of O stars at sub-SMC metallicities. From our 150-massive-star catalogue in the 1/10 Zsun dwarf galaxy Sextans A, we have analyzed the spectra of 50 of the hottest O stars and obtained their production rates of Hydrogen and Helium ionizing photons. By contrasting these results against studies of the interstellar medium, we can determine the average fraction of ionizing photons that escape from Sextans A and better understand the role of dwarf galaxies in the epoch of reionization.

04) **Uroš Meštrić**
University of Milano (email: uros.mestric@inaf.it)

Very massive stars - powerful factories of Lyman continuum radiation

Investigating tiny structures (<100pc size) inside of the galaxies until recently was only feasible at lower redshift. Thanks to the new stellar evolutionary models and synthetic spectra of very massive stars (VMS, M>150Msol) as well as the availability of precise lensed models we can properly interpret and analyze morphological and spectroscopic properties of a young massive star cluster (YMC) at cosmological distances. I will present the YMC dubbed as 5.1l detected at z=2.37 and located in Sunburst Lyman-continuum (LyC) galaxy. We investigated and confirm the presence and segregation of VMS in the central parts of the 5.1l YMC.
Furthermore, we find that the fraction of LyC radiation generated from the VMS is not negligible. Our estimates indicate that YMC harbor around 400 VMS which is 1% of the total population of O-type stars in the cluster (stars capable of producing LyC radiation). Moreover, we estimated that 15% of LyC radiation emitted by YMC is produced by VMS and the rest is generated from less massive O-type stars.

05) **Anne Verhamme** (Review)
University of Geneva, Switzerland (email: anne.verhamme@unige.ch)

Searching for the sources of cosmic reionisation

06) **Eloïse Vitte**
Affiliation: University of Geneva / ESO Chile (email: eloise.vitte@unige.ch)
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Classifying Lyman-alpha emitting galaxies with different spectral shapes in the MUSE Extremely Deep Field

It has been recently found that the Hydrogen Lyman-alpha (Lya) line, the brightest UV-line of high-redshift galaxies, shows a huge variety of shapes which is caused by many factors at different scales, from the interstellar medium (ISM) to the intergalactic medium (IGM).
From a theoretical point of view, double-peak Lya emission line profiles provide a way to characterise the gas exchanges between galaxies and their circumgalactic medium.
We can also learn about the epoch of reionization thanks to the peak separation tracing the escape of ionizing photons and quantify the evolution of IGM attenuation with redshift.

I will present a systematic classification of the spectral shapes of Lya emission lines to understand the general population of high-redshift Lya emitting galaxies (LAEs), using the unprecedented deep data from the MUSE eXtremely Deep Field (MXDF, 140 hour exposure time).

I find double-peaked galaxies occupying a wide range of peak separation values varying from 90 km/s to 2000 km/s with a mean value of 414 ± 61 km/s. 166 LAEs have a peak separation under 400 km/s and $\sim$5% of the sample is triple-peaked suggesting that they are potential LyC leakers.
Moreover, the blue-to-total flux ratio (B/T) distribution of the double-peak sample shows that a majority of the galaxies have an extreme B/T (B/T < 0.2 and B/T > 0.8): either a very red dominant Lya line or a very blue dominant Lya line. The systemic redshifts are needed to confirm the high fraction of extreme B/T.
I derive a universal fraction of double-peak for the first time by cleaning the sample from the observational limitations. My main result is that $\sim$49% of the LAEs present a double-peak Lya emission line. By looking at the evolution of the double-peak fraction with redshift, the decrease of the number of double-peaked galaxies evolves a lot: from 82% at z$\sim$3 to around 40% at z$\sim$4 and reaching 0% at z > 6.5.

My results suggest that we can trace the evolution of IGM attenuation with double-peak fraction.
Moreover, the need of secure systemic redshifts for LAEs is crucial in order to better constrain the nature of the double-peaks. Statistical samples of double-peaks and triple-peaks are a promising probe on the nature of the sources responsible of the reionization of the Universe.

07) **Zhihui Li**
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Extracting Properties of the Galactic Environment via Lyα Radiative Transfer Modeling in a Multiphase, Clumpy Medium

The Lyα emission line encodes abundant physical information about its surrounding gaseous medium in a galactic environment. Nevertheless, the resonant nature of Lyα complicates the modeling and interpretation of the line profile. In this talk, I will present the recent developments of Lyα radiative transfer (RT) modeling in a multiphase, clumpy medium and how the model helps us interpret observed Lyα spectra in a more physically realistic context. I will then present a new application of the model, which is to fit the KCWI-observed radially-varying Lyα profiles of a sample of $z \sim 2$ extreme emission line galaxies in a spatially-resolved manner. Our model successfully reproduces the radial trends of several Lyα spectral properties, including the peak flux ratio, peak separation and flux at the line center, and we reveal the physical reasons for such spatial variations from an RT perspective. Finally, we show that when combined with down-the-barrel UV absorption line observations, our modeling suggests a self-consistent picture of the circumgalactic medium and the galactic fountain.

08) **Jeremy Blaizot**
Centre de Recherche Astrophysique de Lyon (email: jeremy.blaizot@univ-lyon1.fr)

Simulating the many shapes of the Lyman-alpha line

The Lyman-alpha (Lya) line is a powerful and versatile probe of distant galaxies, containing important information about the inflowing and outflowing motions of the gas through which Lya photons scatter. To develop our understanding of this probe, we post-process a zoom-in radiation-hydrodynamics simulation of a low-mass ($M \sim$ 10^9 $M\odot$) galaxy at z = 3 to 4 to construct 22,500 mock spectra in 300 directions at 75 different times. Remarkably, we show that one single galaxy can reproduce with high accuracy the broad variety of a large sample of spectroscopically observed Lya line profiles. While most mock spectra exhibit double-peak profiles with a dominant red peak, their shapes cover a significant part of the parameter space occupied by observed galaxies in terms of e.g. peak velocities, peak separation, and blue-to-total ratio. This diversity mainly originates from radiative transfer effects at both ISM and CGM scales, and strongly depends on galaxy inclination, evolutionary phase, and aperture effects. Red-dominated lines preferentially arise in face-on directions during post-starburst outflow episodes and trace Lya-bright phases. Conversely, accretion events usually yield symmetric double peak profiles in the edge-on direction and are associated with lower Lya luminosities. While resonant scattering effects at < 0.2 Rvir are responsible for the broadening and velocity shift of the red peak, the more extended CGM appears i) to act as a screen – removing photons from the aperture at wavelengths that depend on the kinematics of the volume-filling gas – and ii) to be the main driver of the observed peak separation. Overall, the ability of simulations to reproduce observed Lya profiles and link their properties with galaxy physical parameters offers encouraging new perspectives to use Lya as a probe of the mechanisms that regulate galaxy formation and evolution. Notably, our study implies that deeper Lya surveys may unveil a new population of blue-dominated line profiles tracing inflowing gas.

09) **Emma Giovinazzo**
University of Geneva (email: Emma.Giovinazzo@unige.ch)

Modelling LAEs in the Epoch of Reionization with OBELISK: Exploring the Connection Between Lyman-a Spectra and Lyman-Continuum Escape

Lyman-a emitters are a uniquely useful class of galaxies for the study of the end of the Epoch of Reionization. However, the resonant nature of Lyman-a makes the interpretation of this line challenging, requiring the use of appropriate radiative transfer codes.
We will present results of synthetic observation of the Lyman-a line for a sample of UV-selected galaxies from the OBELISK simulation at z=6, performed with the RASCAS radiative transfer code. We will discuss the properties of the Lyman-a line and investigate how the Lyman continuum escape fraction from the radiative transfer results compares to the value inferred from proposed Lyman-a based estimators such as the Lyman-a peak separation.
Lastly, we will present the effects of the dust distribution on the Lyman-a line by comparing two different dust models.

10) **Silvia Almada Monter**
Max Planck Institute for Astrophysics (email: almada@mpa-garching.mpg.de)
Co-author: Max Gronke

Radiative transfer simulations of Lyman escape through anisotropic gas distributions

One of the crucial puzzles yet to be solved by modern astrophysics is how Lyman continuum (LyC) photons escape their host galaxies to reionize the Universe. Since Lyman-alpha (Lya) photons probe the same neutral hydrogen as LyC, the bright Lya line is often used to infer the ionizing escape fraction and trace the physical conditions of gas through which these photons travel. However, decoding this information from the Lya line profile is far from being an easy task. So far, most attempts have relied on isotropic models that fail to represent real-life scenarios accurately. In this talk, I will discuss results of Lya radiative transfer simulations that were performed on anisotropic settings with different column density configurations. In particular, we added low-column density channels ('holes') in the neutral gas distribution and investigated the effects on the Lya profile. I will show how the extent of the low column density channels (both along and off the line-of-sight) affect Lya spectral quantities, such as the flux level near the line center and how they are related to the global and line-of-sight measured ionizing escape fraction. If time allows, I will discuss observations of galaxies that display unusual spectra, such as the triple-peaked profile in the SunBurst Arc galaxy, in the context of my results.

11) **Andrea Ferrara** (Review)
Scuola Normale Superiore, Pisa Italy (email: andrea.ferrara@sns.it)

What regulates the escape of ionizing radiation from galaxies?

I will discuss the problem of the escape faction of LyC photons from early galaxies and its dependence on the global properties of galaxies from a theoretical perspective. This discussion will be put in the context of the recent JWST results for the most distant galaxies which are revealing a new population of massive and blue galaxies ("blue monsters") at z>10.

12) **Valentin Mauerhofer**
Kapteyn Institute, University of Groningen (email: v.mauerhofer@rug.nl)
Co-authors: Joakim Rosdahl, Anne Verhamme, Jérémy Blaizot, Harley Katz

Predicting the LyC escape from SPHINX20 galaxies using UV continuum and absorption line properties

The escape fraction of ionizing photons from galaxies is a key quantity to understand the process of Reionization of the Universe. However, this quantity is not directly observable, especially at high redshift, where the neutral Intergalactic Medium absorbs all ionizing photons. I will present a method to indirectly infer the properties of Lyman continuum escape, based on the UV continuum properties and the SiII 1260A and CII 1334A absorption lines obtained from the galaxies of the radiation-hydrodynamics simulation SPHINX20 (Rosdahl et al 2022).
After building mock spectra of absorption lines and computing the escape fractions from those simulated galaxies, I use random forest model algorithms to make predictions of escape fractions based on observables such as the UV magnitude, the beta slope, the equivalent width of absorption lines and other line properties. I will present how these models perform to predict both the escape fractions of ionizing photons and the total Lyman continuum luminosities escaping from galaxies.

13) **Joe Lewis** (Keynote Presentation)
ZAH, University of Heidelberg, Germany (email: Joe.Lewis@uni-heidelberg.de)

Ionizing luminosities and photon budget in Cosmic Dawn III

Investigating the escape of LyC radiation is key in interpreting constraints on Reionization. To that end, increasingly detailed numerical simulations have begun to shed light on the complex relationship between the properties of early galaxies and their LyC escape fractions. We leverage the excellent agreement of the fully coupled Cosmic Dawn III RHD simulation with constraints on Reionization and the galaxy population, to study the UVLF, ionizing escape fractions, and ionizing photon budget high redshift galaxies.

We find low mass galaxies drive the initial stages of Reionization, owing to a steep negative correlation between halo mass and LyC escape fraction. In the later stages of the EoR, higher mass galaxies take over, due to strong radiative suppression in lower mass galaxies. Haloes more massive than 10^{11} $M_{\odot}$

have escape fractions of a few percent. Dust has a small impact, further reducing the escape fraction in massive haloes.

14) **Seok-Jun Chang**
Max Planck Institute for Astrophysics (email: sjchang@mpa-garching.mpg.de)

The dynamic duo: Lya & Mg II as tracers of cold gas in CGM

The maze of cold gas galaxies form and how ionizing photons escape through this maze is still an outstanding puzzle. As the direct observation of ionizing radiation is difficult at very high redshifts, we need an observational proxy to investigate the cold gas structure. JWST allows us to observe Mg II resonance doublet in the epoch of reionization as the proxy. Due to its resonant nature, Mg II doublet includes the physical properties of the cold medium via scattering processes - akin to but also very different from Lyman-alpha. In my talk, I will show results from 3D Monte-Carlo radiative transfer simulation of Mg II and Lya through homogeneous and multiphase media. The simulated results highlight the similarities and differences in escaping Mg II and Lya. I will also present clear observational features of Mg II spectra as “smoking gun” for ionizing photon escape. In the end, I will discuss how different metal resonant doublets can be a powerful tool through scattering processes.

15) **Ivan Kostyuk**
Max Planck Institute for Astrophysics (email: ivkos@mpa-garching.mpg.de)
co-authors: Benedetta Ciardi, Dylan Nelson, Andrea Ferrara, Annalisa Pillepich

Investigation of Lyman continuum escape of high redshift galaxies

In this presentation, I will examine the mechanisms of Lyman continuum photon escape from high redshift galaxies during the era of reionization. Using techniques such as post-processing with Monte Carlo radiative transfer and semianalytic modeling, I will investigate the correlation between the physical characteristics of galaxies, subgrid models for gas, and the escape of these photons for galaxies in the TNG50 cosmological simulation. Additionally, I will analyze the implications of these findings on our current understanding of the density of LyC photons escaping into the intergalactic medium.

16) **Louise Seeyave**
University of Sussex (email: l.seeyave@sussex.ac.uk)

FLARE Simulations: the ionizing properties of galaxies in the Epoch of Reionization

Understanding the production of Lyman-continuum photons in galaxies is key to describing the process of reionization. With the recent launch of the James Webb Space Telescope, we are finally able to observe high-redshift galaxies and infer their ionizing properties. What does theory predict, and how do the latest observations compare against it?

In this talk, I will explore this question using FLARES: the First Light And Reionization Epoch Simulations, a suite of cosmological hydrodynamical zoom simulations focused on galaxy formation and evolution at z>5. Its unique simulation strategy allows a large effective area to be probed, with emphasis on overdense regions where massive galaxies are more likely to form. I will present trends for the ionizing emissivity and ionizing photon production efficiency of galaxies in FLARES - how they relate to both physical properties and observable properties (such as the UV continuum slope and the OIII equivalent width).

17) **Callum Witten**
University of Cambridge (email: cw795@cam.ac.uk)
Co-authors: Debora Sijacki, Nicolas Laporte, Sergio Martin-Alvarez

JWST reveals galaxy mergers driving Lyman-alpha emission at z >7

One of the key, unsolved questions in modern-day astronomy regards the sources of the ionizing photons that drove reionization. Recent debates focus on whether a hard radiation field emanating from a single galaxy, or an enhanced radiation field provided by an overdensity of associated objects can produce the required ionizing photons to create the ionized bubbles that are observed at z >7. Observations of Lyman-alpha emitters (LAEs) resident in significant overdensities (protoclusters) have been complicated by the detection of AGN candidates additionally present within many of these bubbles. However, we present results from JWST/NIRCam imaging that reveal, for the first time, resolved z >7 observations of LAEs, giving new insights into their intrinsic properties. These new observations indicate all three known LAEs at z >7, that have been observed by NIRCam, are undergoing mergers that were previously unresolved by HST. We therefore postulate a third solution to this unsolved mystery – Lya emission driven by interactions with a companion. We use spectroscopic and photometric observations in combination with simulations of interacting systems in order to understand the effects of galaxy mergers at high-redshifts on both the escape fraction and the intrinsic emission of Lya photons. We conclude that, while galaxy mergers can have varying effects on the escape fraction dependent on the merger configuration, these interactions clearly drive star-formation and furthermore lead to significant, temporary reductions in the neutral fraction surrounding the system, hence facilitating the excess Lya emission observed in these galaxies. Moreover, we additionally include new results indicating one of our sample is likely resident within a protocluster.

18) **Chris Byrohl**
ITA Heidelberg (email: chris.byrohl@uni-heidelberg.de)
Co-authors: Dylan Nelson

The Lyman-alpha cosmic web in TNG50

The cosmic web can potentially be observed in direct emission through the Lyman-alpha line. While luminous Lyman-alpha emitters are already an established powerful tracer of the matter distribution in the high-redshift universe, the implications of the faint Lyman-alpha glow within the cosmic web (away from luminous emitters) remains to be explored. In this talk, I will characterize the Lyman-alpha

cosmic web using radiative transfer simulations on top of the cosmological magnetohydrodynamical galaxy formation simulation suite IllustrisTNG across different spatial scales and evaluate the feasibility for the Lyman-alpha cosmic web's future detection. I show the complex trajectories taken by Lyman-alpha photons on their way towards an observer, along with a discussion of the origins of these largest Lyman-alpha structures in emission, their underlying halo population, and commonly traced gas properties.

19) **Yucheng Guo**
Centre de Recherche Astrophysique de Lyon (yucheng.guo@univ-lyon1.fr)
Co-authors: Roland Bacon, Lutz Wisotzki, Thibault Garel, Jérémy Blaizot

The Average Physical Properties of Lyman-alpha Haloes in the MXDF

Based on the deepest spectroscopic observations ever made by MUSE in the Hubble Ultra Deep Field, we present a detailed analysis of the average properties of diffuse Lyman-alpha haloes (LAHs) around star-forming galaxies at redshifts between 3 and 6. The extremely deep observation enables high-confidence detections of low-luminosity Lyman-alpha emitters (LAEs, L(Lya, median) $\sim 10^{41.1}$ erg/s)). By stacking 369 spectroscopically confirmed LAEs, we reach a surface brightness limit of approximately 10^{-21} erg/s/cm^2/arc^2, enabling the detection of extended Lyman-alpha emission out to a distance of 270 kpc in the median-stacked surface brightness profile, after carefully correcting for systematic offsets. We compare our observations with simulations and discuss the physical origin of extended Lyman-alpha emission. Our results suggest that LAHs are powered by the central galaxies in the inner 30 kpc, influenced by infalling cool gas at 30-60 kpc, and dominated by photons from surrounding galaxies at larger radii. Our findings provide important insights into different components of the LAHs and have important implications for future studies of the CGM.

20) **Andrea Bolamperti**
European Southern Observatory (ESO), University of Padua (email: andrea.bolamperti@eso.org)
Co-authors: Joël Vernet, Anita Zanella

The origin of the Lyα emission from the polarized spectrum of a star-forming high-z galaxy

Lyα emission is the strongest tracer of recombining ionized hydrogen in young, star-forming galaxies, but its origin is still debated. Its resonant nature makes it a challenging line to interpret: the origin of the emission (i.e., scattering from star-forming regions, inflowing cooling gas, shock-heated gas by supernovae and galactic winds, fluorescent radiation from an ionizing field) and the geometry of the circumgalactic medium are still unclear. Current observational efforts focused on the Lyα surface brightness (revealing the spatial diffusion process of Lyα photons) and spectral profile (encoding information on the mechanism broadening and shifting the spectral line). To reproduce and interpret observations several models have been developed, but it is unclear how physically realistic they are, mainly because widely different models provide similar spectra. We propose to disentangle such models by observing the polarization of the Lyα emission.

In this talk, I will present new spectropolarimetric VLT/FORS2 observations of a clumpy star-forming galaxy at z~3.5. I will show how polarization, combined with recently developed models, shed new light on the origin of the Lyα emission and the geometry of the scattering medium.
I will discuss the implications of these results on the evolutionary scenario of primordial galaxies. They allow us, together with the definition of the neutral hydrogen galactic structure, to constraint the feedback and the lifetimes of star-forming clumps. They play a central role in high-resolution hydrodynamical simulations recipes, whose results are essential to be compared with present and future observations.

21) **Alexander Navarrae**
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Characterizing Strongly-Lensed Lyman-Alpha Galaxies at z > 4

Lyman-alpha is one of the most important tools for studying star-forming regions in young galaxies. As Hydrogen's brightest recombination line, it is an excellent tracer for star formation. And through radiative transfer, Lyman-alpha emission encodes information on the spatial distribution of neutral Hydrogen. Previous studies of high-redshift Lyman-alpha Emitters (LAEs) have measured effective sizes, but have been limited in Lyman-alpha spatial resolution. We present six strongly gravitationally lensed LAEs at $4.1 < z < 5.2$ with high signal-to-noise HST narrowband imaging isolating Lyman-alpha. Broadband imaging from HST (rest-frame UV) and Spitzer (rest-frame optical) is used in SED fitting, providing physical context to the LAEs. Additionally, models of the lenses are used to determine the intrinsic, source-plane properties of the LAEs, such as mass, brightness, and physical scale. We examine the LAE morphologies in Lyman-alpha and the stellar continuum, finding that they fall into two broad categories: extended Lyman-alpha emission concentric with the stellar continuum, and clumpy Lyman-alpha emission dispersed among the stellar continuum. The bimodality of this sample suggests that LAEs in the distant universe are not a homogeneous class of objects.

22) **Riley Owens**
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Connecting Lyα and LyC escape with a gravitationally lensed, super star cluster at cosmic noon

The physical processes that control the escape of ionizing Lyman continuum (LyC) photons from a galaxy are poorly understood, and are likely not isotropic. LyC escape physics should depend on the local properties of the interstellar medium, which can vary on the physical scales of individual star-forming regions. Limited instrumental coverage of resolved LyC radiation at low redshifts and the angular diameter evolution with redshift jointly mean lensed galaxies at redshifts z~2-4 offer the smallest scales we can resolve LyC escape. A valuable tool to identify LyC escape methods is Lyα

emission, since it strongly interacts with the same HI and dust as LyC. Its complex radiative transfer process encodes significant information about the HI morphology and kinematics of the galaxy. In this talk, I will present results connecting Lyα and LyC escape in the Sunburst Arc, a z=2.37 strongly lensed galaxy with LyC emission resolved to a single region ≲20 pc across in a young super star cluster. The strong lensing creates multiple images of the LyC-leaking region, as well as images of different, non-leaking regions of the galaxy. We find great diversity among the Lyα profiles observed along different lines of sight into various locations inside the galaxy, with a differing number of peaks and relative peak strengths. We directly fit the profiles to constrain a large number of common Lyα parameters (such as peak separation, peak FWHM, EW, and more). Briefly, we find the leaking region has a narrow peak separation (~330 km/s), a stronger Lyα EW (~25 Å versus ~10 Å in the non-leaking regions), and other signatures of high LyC escape. We analyze the mutual dependence of the Lyα parameters, as well as their relation to LyC escape. We highlight the correlations and anticorrelations from this, and attempt to offer an explanation for the diversity of observed Lyα profiles. The most likely explanation supports the existence of a mirror-like HI geometry that effectively reflects Lyα photons into our view, far (≳270 pc) from their suspected origin in the LyC-leaking region. This might explain why we observe central Lyα peaks—closely connected to LyC escape—in areas of the galaxy that do not leak LyC. This would emphasize the stochasticity of Lyα radiative transfer and the highly complex relation between Lyα and LyC escape at scales resolved below the size of a galaxy. This will be an important lesson as the number of high-redshift, lensed galaxies grows and JWST and upcoming ELTs target them with unprecedented resolution.

23) **Ivan Kramarenko**
Geneva Observatory (email: im.kramarenko@gmail.com)
Co-authors: J. Kerutt, P. Oesch et al.

Towards Better Understanding of Lyman Photon Escape in z > 3 Lyman-alpha Emitters in the JWST Era

Among many groundbreaking studies at high redshifts, the impressive infrared capabilities of JWST have enabled systematic studies of the gas kinematics and spatially-resolved star formation for representative samples of Lyman-alpha emitters (LAEs) at redshifts up to six. In this work, we perform a joint analysis of the rest-frame optical spectra from the NIRCam/grism observations from FRESCO and the rest-frame UV spectra from the VLT/MUSE observations in the GOODS-South field. We use the optical emission lines to determine systemic redshifts of ∼100 LAEs at z > 3 and measure an average Lyman-alpha (Lya) velocity offset, dv(Lya) ∼190 km/s, that is consistent with the expanding shell models. In agreement with previous studies of LAEs at lower redshifts, we find that dv(Lya) strongly correlates with the Lya peak separation and FWHM, and anti-correlates with the Lya EW, suggesting that the neutral hydrogen column density plays a central role in the escape of Lya photons during the entire post-reionization era. In addition, we estimate the Lya escape fraction, fesc(Lya), using the dust-corrected Lya to Ha ratio and find that fesc(Lya) exceeds 50% for the majority of bright (L(Lya) $> 10^{42.2}$ erg/s) LAEs at 5 < z < 6, implying low column densities and a dust-free, highly ionized ISM. Finally, we use the high-resolution JWST/NIRCam imaging to conclude that the red and the blue components of the double-peaked Lya line profiles in some cases might originate from regions showing substantially different kinematic properties of the gas. Our results demonstrate the special importance of JWST to the understanding of Lyman photon escape in distant LAEs.

24) **Matthew Hayes** (Keynote Presentation)
Stockholm University (email: matthew@astro.su.se)
Co-author(s): Claudia Scarlata, Axel Runnholm, Max Gronke

Lyman-alpha profiles from z=0 to 11. Exploring the inside of ionized bubbles, the evolution of the IGM, and the buildup of galaxy winds

I will present results from four recently published papers, including key results concerning: 1.) how the Ly-alpha emission profiles are formed, 2.) how galaxy winds develop, 3.) how the conditions of galaxies evolve with redshift, and 4.) how we can estimate the size of ionized regions during the Epoch of Reionization.

These conclusions are drawn from an array of observations. Data include ~100 high-resolution spectra of low-z galaxies from HST/COS, ~300 galaxies at z=3-6.5 observed with VLT/MUSE, and 21 galaxies between z=6 and 11 mostly observed with JWST, together with large amounts of ancillary data.
I will demonstrate how the spectral morphology of the line is produced by differing conditions in the interstellar medium, as a result of (mainly photo-ionization) feedback from massive stars. With this knowledge we can use the line profile to quantitatively study the impact that the intergalactic medium has on the line profile. Remarkably, when the known abundance of HI-absorbing IGM clouds are accounted for, the average Ly-alpha profile does not evolve between redshift 0 and 6. Under the assumption that it invariant at higher redshifts still, I will show how Ly-alpha emission observables can track the growth of ionized regions during the reionization epoch.

25) **Anne Hutter**
Cosmic Dawn Center, Niels Bohr Institute, University of Copenhagen
(email: anne.hutter@nbi.ku.dk)

The sensitivity of 21cm signal - Lyman-alpha emitter cross-correlations to the ionisation topology

Whether the few bright or numerous faint galaxies reionised the intergalactic medium during the first billion years remains an outstanding question and depends on how the fraction of ionising photons escaping from galaxies scales, on average, with the galaxy mass. Current and upcoming optical, near-infrared and radio surveys will tackle this question: 21cm emission maps will trace the evolving distribution of ionised regions, while galaxy surveys will sketch the ionising sources and their distribution. Most important, combining these maps of the ionising sources and the ionisation topology opens up the possibility of constraining the ionising properties of the galaxies that are too faint to be observed.
In this context, various theoretical works have explored the benefits of synergising 21cm signal and Lyman-alpha emitter (LAE) surveys, finding that the corresponding cross-correlation functions and power spectra trace the overall ionisation state of the IGM. However, the small-scale (<3cMpc) 21cm-LAE cross-correlation function values derived from different simulations differ. Whether these differences are signatures of different reionisation scenarios or numerical and modelling limitations remains unclear.

To tackle this issue, we have derived an analytical expression for the 21cm-LAE cross-correlation function during reionisation, which opens up the possibility of investigating the nature of these differences. In this talk, I will discuss their origins and explain how the 21cm LAE cross-correlation function traces not only the overall ionisation state of the IGM but also the ionisation topology and hence the galaxy population driving reionisation and how the ionising escape fraction depends on galaxy mass.

26) **Rui Marques-Chaves**
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Complex Lyman-alpha profiles in the UV-brightest galaxies known: evidence of outflowing and inflowing gas, and strong Lyman continuum leakage

UV-bright star-forming galaxies probe intense star formation, thus high production of ionizing, Lyman continuum (LyC) radiation. These sources were believed to be extremely rare at the Epoch of Reionization, pointing to a negligible contribution to cosmic reionization. However, James Webb Space Telescope (JWST) observations are now discovering many UV-bright sources at z>7, with volume densities in strong tension with existing simulation models for galaxy formation. Furthermore, recent works are finding remarkably UV-bright star-forming galaxies at intermediate redshifts (z∼2-4), many of which are prodigious ionizing sources. These combined results are enigmatic, however, may change our understanding of the nature of very UV-bright galaxies and the potential role these sources play in cosmic reionization.

In this talk, I will present recent results on a new sample of very UV-luminous star-forming galaxies at z=2-4 discovered using the Baryon Oscillation Spectroscopic Survey database of the Sloan Digital Sky Survey. These sources show apparent magnitudes rivaling those of bright QSOs, but without any hint of AGN activity. Instead, they are characterized by very young stellar populations (<10 Myr) and very efficient star formation mode (SFRs∼500-1000 Msun/yr, sSFR>50-100 Gyr^-1, E(B-V)∼0), possibly representing early stages of strong starbursts at high redshift like the ones recently uncovered with JWST at z > 7. The three highest-redshift sources in this sample show extreme LyC leakage, up to fesc(LyC)∼90%, being the most powerful ionizing sources identified so far among the star-forming galaxy population. Follow-up observations reveal complex Lyman-alpha (LyA) profiles, including blue-dominated LyA peak emission and triple-peaked shapes, suggestive of massive inflows and large escape of ionizing photons. I will highlight some unique properties observed in these sources including high-resolution LyA profiles, high S/N LyC emission, stellar populations, nebular emission, and SEDs. Finally, I will address the general properties of these UV-bright sources and discuss possible implications in the broad context of galaxy formation and cosmic reionization.

27) **Josephine Kerutt**
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Co-authors: Pascal Oesch, Ivan Kramarenko

Combining MUSE, HST and JWST data to better understand the connection between Lya and LyC emission

It has become clear in recent years, that the most important contributors of the ionising Lyman continuum photons at the epoch of reionisation are star-forming galaxies. To better understand their properties, we look at a sample of Lyman alpha emitters (LAEs) from MUSE at intermediate redshifts z=3-6.7 and find 12 Lyman continuum leaker candidates (Kerutt et al. in prep.) in the Hubble Deep Ultra Violet (HDUV) legacy survey (Oesch et al. 2018). I will present our analysis of these objects, which have estimated escape fractions between 22% and 90%, assuming a high transmission in the intergalactic medium (IGM). However, contrary to observations at lower redshifts and predictions from models (e.g. Verhamme et al. 2017; Vanzella et al. 2020; Izotov et al. 2021), we do not find a strong correlation between the LyC escape fraction and the properties of the Lya line, such as the peak separation and the Lya equivalent width. A possible explanation for this discrepancy would be that the Lya photons do not originate from the same star-forming regions as the Lyman continuum emission we detect. We investigate this by using data from the JWST program FRESCO (PI Pascal Oesch), providing Ha line maps, which we compare to the Lya positions from MUSE.

28) **Keunho Kim**
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Co-authors: co-authors: Matthew B. Bayliss, Jane R. Rigby, Michael D. Gladders, John Chisholm, Keren Sharon, Håkon Dahle, T. Emil Rivera-Thorsen, Michael K. Florian, Gourav Khullar, Guillaume Mahler, Ramesh Mainali, Kate A. Napier, Alexander Navarre, M. Riley Owens, and Joshua Roberson
University of Cincinnati

How ionizing radiation escapes from compact star-forming regions in the Sunburst galaxy

The escape mechanism of ionizing (Lyman-continuum) radiation from young star-forming galaxies is crucial to understanding how the Universe was reionized. We investigate the characteristics of a compact star-forming complex with leaking LyC radiation in the gravitationally lensed Sunburst galaxy at redshift 2.4. This galaxy provides unique opportunities to examine the physics of LyC escape down to tens of parsecs through a combination of Hubble Space Telescope's clean imaging (high angular resolution) and the zoom-in effect of lensing. We measure the key physical parameters of the leaking complex including UV-continuum slope, Lyman-alpha emission, Balmer line, and oxygen ([O III] and [O II]) line ratio based on narrowband HST images. Remarkably, we find very blue UV slopes (-2.9) in the multiply magnified regions of the leaking complex, which is bluer than typical of star-forming galaxies as well as non-leaking regions in the galaxy. Moreover, there are significant correlations between the physical parameters of the leaking complex, such that bluer UV slopes are related to higher Ly-alpha escape fraction and oxygen line ratio. Our findings would suggest that highly ionized, compact star-forming regions with little dust promote the escape of LyC radiation in a galaxy.

29) **Jan Eldridge** (Review)
The University of Auckland (email: j.eldridge@auckland.ac.nz)

Binaries, supernovae, black holes and stochasticity effects on Lyman radiation escape

Binaries have, over the past decade, become widely accepted as important to understand anything involving stellar populations. In this talk I will outline why binary stars introduce important evolution pathways that are important as sources of Lyman continuum radiation. These include the stars when still fusing elements in their core, as well as after their deaths in X-ray binaries. I will show the evidence from the gravitational wave transient catalogue that significant mass transfer must occur in X-ray binaries producing significant Lyman continuum radiation.

I'll then discuss supernova feedback and how recent findings suggest it should be weaker than previously thought. Because whether a supernova occurs at core-collapse is uncertain if a black hole if formed. In addition, the latest BPASS stochasticity investigation led by Elizabeth Stanway shows that stochastic effects may weaken supernova feedback further. Only using all observational constraints, both electromagnetic waves and gravitational waves will be begin to understand these complex stellar evolution open questions.

30) **Emil Rivera-Thorsen**
Stockholm University (email: trive@astro.su.se)
Co-authors: Matthew Hayes, Jens Melinder

What does the typical LyC leaker look like? Results from a LyC-selected leaker survey in the Hubble Ultra Deep Field

When conducting searches for Lyman-Continuum leaking galaxies, it is standard to rely on a set of pre-selection criteria to scout out promising leaker candidates. Among these criteria, examples like e.g. UV brightness and slope, Lyman-alpha brightness, morphology and spectral line shape, [O III]/[O II] ratio, or combinations of these, are popular. They are relatively easy to observe, are physically well motivated, and have a good success rate in predicting LyC escape. But do they cover the entire population of LyC-emitting galaxies? Could there be ionizing emission out there from surprising sources, in which we did not expect to see it? How many, if any, leakers do we unknowingly discard when applying these pre-selection criteria, and how much ionizing radiation do they account for?

In this talk, I present a search for Lyman Continuum emitters that turns the usual procedure on its head in an attempt to avoid these biases. In archival UV observations of the Hubble Ultra Deep Field (HUDF), we have extracted every source we could detect, and subsequently worked our way backwards to determine whether each source detected is a case of escaping ionizing radiation, or - as in the vast majority of cases - is non-ionizing radiation from a lower-redshift galaxy. This method should in principle catch all LyC emitters in the redshift range $2 < z < 3.5$, regardless of how well they resemble the statistically typical leaker of existing samples. I present the results of this work, and discuss their implications for our understanding of LyC escape from galaxies and the ionization history of the Universe.

31) **Gonzalo Prieto Lyon**
DAWN - Niels Bohr Institute - Copenhagen University (email: gonzalo.prieto@nbi.ku.dk)

The transmission of Lyman-alpha from UV-faint galaxies: low velocity offsets in lensed z ~ 3 − 6 galaxies

We still lack a complete understanding of the transmission of Lyman-alpha (Lya) through the intergalactic medium (IGM) during reionization, due to the degeneracy between Lya attenuation and the line profile emitted from galaxies. Large shifts of Lya photons toward wavelengths redward of systemic have been suggested to boost transmission in the neutral IGM.

Before JWST, Lya velocity offsets were not well established at high redshift due to the difficulties of observing emission lines that trace systemic redshifts. Thanks to the NIR capabilities of JWST, we have a new window on our understanding of Lya transmission at z>3 through rest-frame optical spectroscopy. I will present an analysis of 12 UV-faint (MUV > -20) galaxies at z∼3-6 observed with MUSE and JWST/NIRSpec, in the GLASS-ERS program. We find very low velocity offsets in our sample, compared to those found in brighter galaxies. I will describe trends between the velocity offsets, the broadness of optical emission lines, and Lya equivalent widths to investigate the mechanism for the relationship between UV luminosity and Lya velocity offsets. I will connect these results with ongoing work, where we are measuring high resolution Lya line profiles and velocity offsets for a sample of ∼70 z∼6 galaxies with MMT/Binospec and JWST/NIRCam grism spectroscopy from FRESCO. I will discuss the implication of our results for Lya transmission during reionization and for aiding the identification of large ionized bubbles.

32) **Sara Mascia**
INAF - Osservatorio Astronomico di Roma (email: sara.mascia@inaf.it)
Co-author: Laura Pentericci

Reionization's labyrinth: how to escape following the indirect indicators' thread

In the recent years several LyContinuum indirect indicators have been extensively tested at low and intermediate redshifts: these are physical and observational properties that have a direct link to the leakage of LyC photons in star forming galaxies. Among them the most robust seem to be a high [OIII]/[OII] flux ratio, a high star formation surface density and a compact size, a steep UV continuum slope, a high EW(Hbeta) and possibly the presence of strong nebular CIV emission.
In this talk I will first present the analysis of a large sample of galaxies at $4.5 \leq z \leq 8$, which include lensed galaxies behind the Abell 2744 cluster observed by the JWST GLASS program and normal field galaxies observed by the JWST-CEERS program. Combining NIRSpec and NIRCam data we determine the physical and spectroscopic properties of such objects, and then infer the escape fraction of ionizing photons based on indirect diagnostics. We then evaluate the ionizing capabilities of star forming galaxies as a function of redshift and magnitude, to assess which sources were the main responsible for reionizing the IGM.
I will then briefly present the analysis of the physical and spectroscopic properties of a sample of z= 3 CIV emitters observed by the VANDELS survey to test if indeed nebular CIV can be also a good LyC indirect indicator.

33) **Anthony Pahl**
UCLA (email: pahl@astro.ucla.edu)
Co-authors: Shapley, Alice ; Steidel, Charles C. ; Reddy, Naveen A. ; Chen, Yuguang ; Rudie, Gwen C. ; Strom, Allison L.

The Connection Between the Escape of Ionizing Radiation and Galaxy Properties at High Redshift

The connection between the escape fraction of ionizing radiation (f_esc) and the properties of galaxies, such as stellar mass (M*), age, star-formation rate (SFR), SFR surface density, and dust content, are key inputs for reionization models, but many of these relationships remain untested at high redshift. In this talk, I present an analysis of a sample of 96 z∼3 galaxies from the Keck Lyman Continuum Spectroscopic Survey. These galaxies have both sensitive Keck/LRIS spectroscopic measurements of the Lyman continuum (LyC) region, and multi-band photometry that places constraints on stellar population parameters. We construct composite spectra from subsamples binned as a function of galaxy property and quantify the ionizing-photon escape for each composite. We find a significant anti-correlation between f_esc and M*, consistent with predictions from cosmological zoom-in simulations. We also find significant anti-correlation between f_esc and E(B-V), encoding the underlying physics of LyC escape in our sample. We also find a lack of correlation between f_esc and stellar age and f_esc and specific SFR, challenging interpretations that synchronize recent star formation and favorable conditions for ionizing escape. Of particular interest is a subsample of 35 galaxies with high-resolution HST imaging, enabling estimates of rest-UV sizes, and thus, SFR surface density, thought to be correlated with f_esc in star-forming galaxies. I will present our exploration of the relationship between f_esc and SFR surface density at z∼3. To date, this is the most comprehensive analysis of galaxy properties and LyC escape at high redshift, and will be used to guide future models and observations of the reionization epoch.

34) **Charlotte Simmonds**
University of Cambridge (email: cs2210@cam.ac.uk)
Co-authors: Sandro Tacchella, Christina Williams, Michael Maseda

Ionising photon production efficiency of LAEs at the tail of the EoR

In this talk I present the results of my work studying the ionising photon production efficiency of 25 bright Lyman-alpha emitters (LAEs) at the end of the Epoch of Reionisation (z∼5.4-6.6). They were detected with MUSE and have been assigned systemic spectroscopic redshifts based on their Lya line profiles. We use the spectroscopic redshifts to estimate the H-alpha emission line using the JWST NIRCam medium band survey, in particular, we use photometry in the F430M, F460M and F480M filters, finding excess flux corresponding to the redshifted H-alpha wavelength for each object.
We estimate the luminosity at rest-frame 1500 Angstroms by fitting the full photometry, including with several HST photometric points, with the SED-fitting software Prospector. We find ultra-violet continuum slopes indicative of young stellar populations with little-to-no dust attenuation. Supported by this, we derive the ionising photon production efficiency assuming no dust attenuation and find a median value of $\xi_{ion,0}$ \sim 2 \times 10^{26}$ Hz/erg. If we perform dust attenuation corrections and assume a Calzetti attenuation law, our values are lowered by ∼0.1 dex. Our results suggest Lyman-alpha emitters at the Epoch of Reionisation have a slightly enhanced $\xi_{ion,0}$

compared to estimations from literature, which correlates positively with the Lyman-α luminosity. This is a first step towards a more complete study using the entire dataset provided by the JWST Advanced Deep Extragalactic Survey (JADES).

35) **Ryan Begley**
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Co-authors: F. Cullen, R. J. McLure, J. S. Dunlop + a number of VANDELS Core Team Members

The VANDELS survey: a measurement of the average Lyman-continuum escape fraction of star-forming galaxies at z=3.5

An important problem related to inferring the timeline of cosmic reionisation is constraining the escape fraction of ionising photons from high-redshift galaxies. Unfortunately, during the reionisation epoch itself (z > 6), direct constraints on the escape fraction are not possible due to significant HI absorption in the intervening IGM. Our best direct constraints must therefore come from galaxies at lower redshift, where the IGM absorption is less extreme. In this project, we have used ultra-deep VIMOS U-band and Hubble Legacy Fields imaging in the CDFS, alongside reliable spectroscopic redshifts from the VANDELS survey, to measure the escape fraction of 148 typical star-forming galaxies at z∼3.5. In this talk I will present statistically significant constraints for the average escape fraction of our galaxy sample, and explore the various relationships between the escape fraction and other galaxy properties (e.g. stellar mass, Lyman-alpha equivalent width). I will also show new results that demonstrate a clear correlation between the escape fraction of Lyman-alpha and Lyman-continuum for VANDELS SFGs at z∼4-5, an exciting first at this redshift. These measurements will play a crucial role in refining models of cosmic reionisation, specifically in highlighting the contribution of typical galaxies to this process and how their Lyman-continuum escape is facilitated.

36) **Anne Jaskot** (Review)
Williams College (email: 08aej@williams.edu)

A Low-Redshift Look at LyC Escape

Because of the opacity of the IGM, directly measuring the LyC escape fraction is not possible in the epoch of reionization. At z∼0, however, IGM attenuation is negligible, and LyC observations at low redshift have given us key insights into the nature of LyC-emitting galaxies. Over the past decade, the number of LyC detections at z∼0 has grown dramatically, with 50 LyC Emitters now known at z=0.3. I will review efforts to identify LyC Emitters, including the recently completed Low-Redshift Lyman Continuum Survey (LzLCS), the largest survey of LyC emission at low redshift to date. With HST UV observations of 66 galaxies, the LzLCS has nearly tripled the number of low-redshift LyC detections, enabling us to systematically test proposed indirect diagnostics of LyC and establish the physical properties of LyC-emitting galaxies. Although LyC emitters span a wide range of properties, strong LyC escape is associated with strong and narrow Ly-alpha emission, high nebular [O III]/[O II] ratios, compact star formation, low dust extinction, weak UV absorption lines, and weak nebular [S II] emission. I will present new multivariate predictions of LyC escape fractions, based on these results. These predictions successfully reproduce LyC observations at z=3, which suggests that low- and high-redshift LyC emitters may share similar properties. Finally, I apply these predictions to z>6 JWST observations and discuss the implications for galaxies in the epoch of reionization.

37) **Peter Senchyna** (Keynote Presentation)
Carnegie Observatories (email: psenchyna@carnegiescience.edu)

Local clues to understanding stellar feedback and ionizing photon production in the early Universe

A unique window has opened onto the physical conditions of the high-redshift Universe with the accumulation of deep JWST nebular spectroscopy. However, these data continue to underscore deficiencies in our understanding of the very metal-poor stellar populations that power them. I argue that understanding the surprises we encounter at high-redshift will increasingly require delving deeper into galaxies in the local Universe. I will first demonstrate this by discussing recent JWST spectroscopy of GN-z11, which revealed a rest-UV spectrum that dramatically departs from theoretical and empirical expectations. Placing this spectrum in a local context reveals evidence for an extremely dense mode of intense star formation which might be encountered in other systems at these highest redshifts, and in which the effects of stellar multiplicity might play an outsized role. Despite their likely crucial role in shaping metal-poor stellar populations across cosmic time, surprisingly little is known empirically about the products of mass transfer in binary and higher-order systems and their impact on their host galaxies. I will discuss results from observations targeting a peculiar star in Leo A which we identify as a likely extremely metal-poor massive stripped star. HST spectroscopy of this object confirms its hot temperature and an anomalously slow stellar wind. I discuss the potential implications of this discovery in the context of modeling ionizing photon production and escape as well as chemical enrichment in distant metal-poor galaxies. Finally, I chart a path towards placing further empirical constraints on these processes with deep observations in the local Universe.

38) **Sophia Flury**
University of Massachusetts Amherst (email: sflury@umass.edu)
Co-authors: Anne Jaskot, Alberto Saldana-Lopez, and the LzLCS

Exploring LyC Escape Scenarios with Stacked Spectra from the LzLCS

We present new insights from the Low-redshift Lyman Continuum Survey (LzLCS) regarding the relationship between feedback and LyC escape. Combined with previous HST/COS surveys, the LzLCS contains a total of 89 galaxies at $z\sim0.3$, the largest sample of low-redshift galaxies with direct LyC measurements. We stack the rest-frame UV spectra of different galaxy populations within the LzLCS to measure average LyC escape fractions (fesc) and to improve constraints on stellar populations and ISM properties. A detailed analysis of the stacks of different types of LCEs and non-LCEs indicates marked differences in stellar populations and star formation history. These differences suggest that episodic star formation and feedback play a significant role in facilitating LyC escape and may explain distinctions between different types of LCEs. For a self-consistent test of the inferred geometry/feedback/LyC escape relationships, we run photoionization models based on the stacked spectra and compare the predicted nebular flux ratios with those of the stacks. The good agreement between the predicted and observed flux ratios lends further credence to the idea that radiative feedback and neutral gas geometry play key roles in the escape of LyC photons from galaxies.

39) **Alexandra Le Reste**
Stockholm University (email: alexandra.lereste@astro.su.se)

The 21cm HI properties of local Lyα-emitting galaxies

The Lyman alpha (Lyα) line of Hydrogen is the intrinsically strongest nebular line in a galaxy spectrum and a critical tool for the study of galaxies at high redshift. However, the resonant nature of the line means it undergoes complicated radiative transfer in the neutral Interstellar Medium (ISM) of galaxies. This makes the connection between galaxy/ISM properties and Lyα morphologies or line profiles unclear, and poses limitations to the use of the Lyα line to its full potential.
In this talk, I will present results from 21cm observations of local Lyα-emitting galaxies from the (e)LARS samples. We have observed 39 of the 42 galaxies with the Very Large Array D configuration (50" resolution), and two with a combination of the D, C B and A configuration (3.5" resolution). These observations allow us to probe and compare both the global and local neutral gas properties of the (e)LARS galaxies. I will show how 21cm and galaxy properties compare to Lyα emission, and what this teaches us on the role of neutral Hydrogen on the Lyα radiative transfer.

40) **Enrique Pérez Montero**
Instituto de Astrofísica de Andalucía - CSIC (email: epm@iaa.es)
Co-authors: C. Kehrig, J.M. Vílchez

Using photoionization models in the softness diagram to Estimate the escape fraction of ionizing photons

The analysis of massive starbursts in the local Universe to measure their photon leaking fraction when no UV observations are available, and thus no possible measurement of the Lyman alpha continuum is possible, could increment significantly the number of this reionization epoch analogs if alternative methods based on optical emission-lines could be applied.

The softness diagram is a tool that can be used to comparatively estimate the hardness of the ionizing spectral energy distribution in ionized gaseous nebulae. The combined use of several high- to low-excitation line ratios can additionally provide estimations of the photon absorption fraction if they are used in combination with photoionization models calculated under different assumptions on the gas geometry.
However, the importance of additional factors affecting this diagram, including metallicity, excitation, or the nature of the assumed ionizing stellar population makes this diagnostic very model-dependent and only Bayesian methods can provide adequate solutions with realistic uncertainties. In this contribution I will present different versions of the softness diagram based on different emission-line ratios, including [OII]/[OIII] or HeI/HeII. This diagram in combination with the code HCm-Teff can provide constrains to this absorption fraction in highly excited metal-poor environments as those in green pea or extremely metal poor galaxies, for which we will examine different results using this method.

41) **Ricardo Amorín** (Keynote Presentation)
University de la Serena (email: ricardo.amorin@userena.cl)

Chemodynamics, feedback and the escape of Lyman radiation in green pea galaxies

The Green Pea (GP) galaxies at redshift $z\sim0.3$ are compelling analogues of primeval galaxies that played a crucial role in reionizing the universe at $z>6$. The remarkable escape of Lyman alpha and Lyman continuum emission from GPs, observed through HST-COS in the far-UV, offers a promising opportunity to study the fundamental physics that governs the escape of Lyman radiation from galaxies with an unprecedented level of detail, which is impossible to match at high-redshifts.

In this presentation, I will discuss fresh insights gained through observational studies of GPs, with a particular emphasis on deciphering their complex ionized kinematics through high-dispersion, long-slit and spatially resolved, spectra. Our findings underscore the ubiquitous presence of highly turbulent gas and ionized outflows, which provide valuable constraints into feedback models and contribute to a better understanding of the intricate interplay among massive star formation, ISM physical properties (ionization and metallicity conditions) and the escape of ionizing radiation.

42) **Adam Enders**
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Co-authors: Bomans, Dominik J., Wittje, Anna

LCE candidates from HeII

Finding low-redshift analogues to Lyman Continuum Emitters (LCEs) in the Epoch of Reionisation currently presents itself as a promising pathway to understand the mechanisms driving the high-energy photon leakage in early galaxies. Due to a lack of unambiguous selection criteria, the current sample size of 'local' LCEs still is appreciably small (N=61).
Here, we show that utilising high-ionisation nebular emission lines, in particular HeII 4686, is a promising approach to expand the sample of known LCEs. Drawn from archival SDSS data (DR12), we present eighteen previously unreported LCE candidates, whose global properties align well with those of high-redshift star-forming galaxies. Having reconstructed their star-formation histories, we find a common pattern among the young stellar populations in these objects, namely a two-stage starburst with ages of $\sim$1 Myr and $\sim$10 Myr.
Motivated by this, we propose a scenario that relates this feature to the escape of LyC photons: The numerous recent supernovae implied by the 10 Myr population may have carved low-density tunnels into the interstellar medium, through which the ionising radiation provided by the 1 Myr population then can escape into intergalactic space. The large ionisation parameters as well as the indications for density-bounded conditions we find throughout our study are supportive of this scenario.
If the LyC photon loss we infer is genuine, our study demonstrates that high-ionisation nebular lines may serve as a powerful selection criterion in the search for LCEs. Moreover, the objects we present would reside among the closest LCEs known to date.

43) **Adele Plat**
University of Arizona (email: adele.plat@iap.fr)

Production and escape of Lyman continuum radiation in metal-poor star-forming galaxies

Many observations and interpretations of emission-line properties of distant galaxies and nearby analogs of primeval galaxies have been proposed to prepare for JWST observations. Until now, these samples have been analyzed in largely independent ways using different prescriptions for the production (stellar population modeling) and transfer (photoionization modeling) of radiation in young galaxies. We compile a wide range of ultraviolet and optical observations pertaining to analogs of primeval galaxies at different redshifts and compare them with versatile, physically self-consistent models of star-forming galaxies including, among others, the leakage of Lyman-continuum photons from density-bounded HII regions and the contribution by an AGN to nebular emission. From the combined influence of model parameters on a wide range of ultraviolet and optical spectral diagnostics, I will discuss how we can learn about the nature of the ionizing source and leakage of ionizing photons in such galaxies.

44) **Cristina Cabello**

Universidad Complutense de Madrid (email: criscabe@ucm.es)
Co-author(s): Nicolas Cardiel, Jesus Gallego

Unveiling the escape of ionizing photons: new insights from a 2D spatially-resolved study

The identification and further study of local analogs of high-z galaxies is key to shedding light on the early Universe and the conditions under which the first sources reionized the IGM. Local analogs have been historically analyzed from their integrated spectra, but recent IFU observations revealed significant spatial variations in the ionizing photon escape fraction. For this reason, 2D spectroscopic information is crucial for obtaining a detailed mapping of the ionizing structure of the ISM and disentangling the mechanisms that allow LyC photons to escape. In this talk, I will present the first results of the 2D spatially-resolved study of UM461 performed with the MEGARA@GTC IFU. Both cosmological simulations and previous observations classified this star-forming galaxy as a potential LyC leaker and reionization epoch analog. In this study, we analyzed the spatial distribution of the physical and kinematic properties of UM461, and tested its LyC-leaker status by using indirect indicators such as the O32 index, [SII] deficiency, and He I emission-line flux ratios. Furthermore, in order to study the impact of the sightline effect, we extracted the spectral information from multiple distinct apertures and estimated the escape fractions of ionizing radiation in different regions of the galaxy. This pioneering work will be soon complemented with a larger sample of local analogs to be observed with MEGARA in the upcoming months, which will yield important statistical conclusions for the whole population of low-z reionization epoch analogs.

45) **Göran Östlin**

Stockholm University (email: ostlin@astro.su.se)
Co-authors: Melinder, et al.

Dissecting the leakiest galaxy in the low-z universe

Among the low redshift (z<0.5) galaxies where the Lyman continuum flux has been measured directly by COS, J1243+46 stands out as the galaxy with the highest estimated escape fraction. Here we will present fresh HST imaging data in many filters, probing the wavelength range from to 850 to 11000 Å in the continuum, as well as several emission lines (Lyman alpha, H-alpha, H-beta, [OII] and [OIII]).

46) **Edmund Christian Herenz**
ESO / Leiden Observatory (email: herenz@strw.leidenuniv.nl)

A 15 kpc outflow cone piercing through the halo of the blue compact dwarf galaxy SBS 0335-052E

The ionising photon leakage from galaxies must occur along channels of low optical depth in the Lyman continuum. Galaxy scale winds and outflows are believed to be responsible for creating these channels. Despite seemingly favourable conditions for the development of star-formation driven outflows in compact low-mass galaxies, observational evidence for such kpc-scale outflows remains rare. This talk will report on an interesting large-scale outflow in a compact low-mass galaxy (SBS 0335-052E) that shares many characteristics of star-forming galaxies in the early universe. The warm ionised phase of the giant outflow was discovered and mapped in Hα and [OIII] λ5007 emission with ESO-VLT/MUSE. The warm neutral phase in and around the galaxy, some of which is probably associated with the outflow, was mapped in in 21cm with NRAO/VLA. I will present a simple geometrical model that is commensurate with the observed structure and I will discuss possible implications for the Epoch of Reionisation.

47) **Antonio Arroyo Polonio** (antonioarroyopolonio@gmail.com)
IAA-CSIC (email: antonioarroyopolonio@gmail.com)
Co-authors: Jose Manuel Vilchez Medina, Jorge Iglesias-Paramo, Carolina Kehrig

Tracing Escape Channels for Lyman Continuum Photons in Extreme Emission Line Galaxies

Extreme Emission Line Galaxies (EELGs) are a class of galaxies presenting extremely high emission line fluxes and EWs. These galaxies are of great interest as important sites of star formation and metal enrichment, and most likely the local analogues of distant, EoR galaxies.

Within an extended observational project using large Telescopes (GTC, VLT) here we present a detailed analysis of a sample of Green Pea galaxies (GPs) observed with MUSE (R∼3000, seeing limit) at the VLT. GPs are a subset of EELGs known for their compact, low-metallicity, and highly ionized star-forming regions.

Maps of the extinction (from Hα/Hβ ratio), ionization structure (using [OIII]/[OII], [OIII]/Hβ, [SII]/Hα, [OI]/Hα line ratios), and density-bounded conditions tracers ([SII]/Hα, [OI]/Hα) -among other properties-, have been produced for over twenty GPs of the sample. In addition, maps of the kinematical properties (e.g. velocity, velocity dispersion) of the ionized gas, and of the (line-free) underlying stellar continuum, have been produced for these galaxies.

Detailed analysis of these maps has allowed us to identify the regions of the GPs where the conditions for LyC escape are most favorable. Regions with lower extinction, low gas density, and positive density-bounded tracers, should favor LyC photons to escape more easily. This analysis has also considered the corresponding maps of ionization parameter (as indicated by [OIII]/[OII]; [OIII]/Hβ), and of kinematical properties (tracers of possible gas outflows).

Studying the escape of Lyman continuum photons from galaxies is complex and requires the understanding of the interplay between the stellar radiation, the interstellar medium, and gas outflows. This work highlights the power of using Integral Field Spectroscopy (versus integrated spectra), in order to infer those 2D ionized gas structures associated to high-energy photons escape regions.

48) **Anna Lena Schaible**
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Co-author: Edmund Christian Herenz

Relation between ionized gas kinematics and Lyα observables in ELARS

The Lyman α (Lyα, λ1216) line is an important signature to find high-z galaxies, but the resonant line transfer requires extremely low optical depths for it to emerge actually from galaxies. Turbulent kinematics may shift enough emitting and absorbing material out of resonance and thereby enhance the probability of Lyα escaping.
We present integral field spectroscopic observations with PMAS at the Calar Alto 3.5 m telescope of 42 galaxies of the "Extended Lyman Alpha Reference Sample". The galaxies are low-z and have high specific star formation rate. We have 2D line of sight velocity maps and velocity dispersion maps from the Hα line of all 42 galaxies and global Lyα properties observed by Hubble space telescope. We compute the non-parametric global kinematic parameter intrinsic velocity dispersion σ_0, shearing velocity v_shear and the ratio of both v_shear/σ_0 and compare our results with kinematical models (GalPaK3D).
We performed a global analysis of the kinematical properties of our sample in concert with their Lyα observables. We find correlations that are supportive that ionized gas kinematics influence the escape of Lyman α radiation from galaxies.

49) **Alberto Saldana-Lopez**
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Co-authors: D. Schaerer (UniGE), J. Chisholm (UTAustin), A. Calabro (INAF), L. Pentericci (INAF), F. Cullen (ROE) and A. Saxena (Oxford)

The ionizing properties of galaxies through the eyes of absorption line spectroscopy

The physical properties of Epoch of Reionization (EoR, $6 < z < 9$) galaxies are still poorly constrained by observations. Recent HST campaigns such as the Low-Redshift Lyman Continuum Survey (LzLCS) -the largest survey to date probing Lyman continuum (LyC) emission at low redshift- have revealed that compact star formation, high ionization parameters, strong and narrow LyA emission, low dust-attenuation and the presence weak absorption lines seem to characterize the spectra of the strongest LyC emitters.

Unfortunately, we need to rely on indirect indicators for LyC radiation since the opacity of the intergalactic medium prevents from any direct detection at $z > 6$. Absorption line measurements have been proved to trace the geometry of neutral and low-ionized gas within the interstellar medium of

galaxies and, together with estimates of the dust attenuation, constitute a promising proxy of the LyC escape fraction.

In this talk, I will present an overview on the advantages of using deep, rest-UV spectroscopy to decipher the ionizing properties of high-z galaxies. Our methodology, anchored and tested at low-z thanks to the LzLCS, allow us to predict ionizing escape fractions and production efficiencies for more than 500 galaxies selected from the VANDELS survey at $3 < z < 5$, the last public ESO spectroscopic survey. The ionizing properties of VANDELS galaxies will be then correlated versus diverse galaxy physical properties. Our findings, if extrapolated to the EoR, imply that the ionizing budget at the EoR was likely dominated by moderately UV-faint, low-mass and dustless galaxies.

50) **Axel Runnholm**
Stockholm University (email: axel.runnholm@astro.su.se)
Co-authors: Matthew Hayes, Bjarki Björgvinsson, Yu-Heng Lin, Jens Melinder, Claudia Scarlata

Creation and Evolution of Lyα halos - clues from low redshift observations.

Lyman α (Lyα) is now routinely used as a tool for detecting high-redshift galaxies and its resonant nature means it can trace neutral hydrogen around star-forming galaxies. Integral field spectrograph measurements of high-z Lyα emitters indicate that significant extended Lyα halo emission is ubiquitous around such objects. We present a sample of redshift 0.23 to 0.31 galaxies observed with the Hubble Space Telescope selected to match the star formation properties of high-z samples while optimizing the observations for detection of low surface brightness Lyα emission.

All seven targets show Lyα emission, with total escape fractions between 0.7% and 37%, and extended Lyα emission. We find Lyα halo to UV scale length ratios around 6:1 which appears marginally lower than high-redshift observations, and halo flux fractions between 60% and 85% —consistent with high-redshift observations—when using comparable methods. However, our targets show additional extended stellar UV emission, indicative of an older more extended stellar population, which we parametrize with a new three exponential component model for Lyα emission. We find that this parametrization does not strongly affect the observed Lyα halo fractions.

Determining how Lya halos are created is a difficult task however, even with our HST Hα observations, due to the low surface brightness of the emission. We have therefore also obtained MUSE observations for five of the seven galaxies which will allow us to examine the Hα distribution to lower surface brightnesses and, additionally, allow us to constrain the spatial distribution of ISM properties, such as ionization levels and other conditions favorable for the escape of Lyman radiation. Here we will present the first early results from this study.

51) **Lena Komarova**
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Co-authors: M. S. Oey, Svea Hernandez, Edmund Hodges-Kluck, Göran Östlin, Angela Adamo, Arjan Bik, Matthew J. Hayes, Anne E. Jaskot, Daniel Kunth, Peter Laursen, Claus Leitherer, J.M. Mas-Hesse, Jens Melinder, T. Emil Rivera-Thorsen, Mattia Sirressi

Haro 11: The Resolved Lyman Continuum Source and Cosmological Implications

Haro 11 is the closest confirmed Lyman continuum (LyC) emitter (LCE) and thus a prime laboratory for studying physical mechanisms responsible for cosmic reionization. It is dominated by three starburst regions Knots A, B and C with widely varying properties, and the initial LyC detection did not resolve the specific LCE knot. We present new HST/COS observations of the three candidate regions in LyC, finding Knots B and C to be the LCEs. Knot C has been earlier predicted to leak LyC based on its highest Lyα escape. However, the strongest LyC detection is from Knot B, despite its highest extinction and neutral covering fraction. The non-detection in Knot A is unexpected, given its density-bounded ionization structure. Interestingly, both of the LCE Knots B and C host ultra-luminous X-ray sources (ULXs) likely associated with accreting black holes. We discuss the possible relative roles of stars and X-ray sources in the LyC leakage of Haro 11, as well as the corresponding cosmological implications.

52) **Timmy Ejdetjärn**
Stockholm University (email: timmy.ejdetjarn@astro.su.se)

Modelling the merger of the blue compact galaxy Haro 11

Blue compact galaxies are a class of galaxies undergoing a burst of star formation. Due to their high star formation rate and low metallicity, blue compact galaxies in the local Universe offer a rare opportunity to investigate extreme environments that are similar to the galaxies at the dawn of galaxy formation. These galaxies are prime candidates to be LyC leakers and could help us understand the conditions during the Epoch of Reionization.

In this work, I have modelled a possible origin history for the blue compact galaxy Haro 11, the closest confirmed LyC leaker, by using N-body + hydrodynamical simulations. By varying the orbital parameters and the individual properties of two galaxies undergoing a merger, I manage to reproduce several key characteristics of the Haro 11 galaxy, including: tidal tail features, star formation rate, stellar populations' masses & ages. For this presentation, I will present how I produced this model from observational constraints and compare the agreement of various quantities between observations and my simulations. I will show how the gas structure and kinematics change during this merger, so as to possibly help the escape of ionising radiation.

53) **Jens Melinder**
Stockholm University (email: jens@astro.su.se)
Co-authors: Armin Rasekh, Göran Östlin, Daniel Schaerer, Matthew. J. Hayes, Axel Runnholm, Yuri Izotov, Natalia Guseva, Yu-Heng Lin, and Trinh Xuan Thuan

The connection between Lyman continuum escape and Lyman alpha spatial distribution

Star-forming galaxies are possibly the major source of ionizing photons driving re-ionization in the early Universe. But given that these photons get absorbed by neutral hydrogen both inside the galaxies where they are produced and in the intervening intergalactic medium it is extremely difficult to detect this so called Lyman continuum (LyC) radiation directly. Nevertheless, over the last few years the number of direct detections of nearby leakers have gone from a few to $\sim$50. By observing LyC radiation from nearby galaxies it is possible to find which conditions need to be met for escape to happen, and possibly be able to predict the escape fraction given the other observed properties of the galaxies. The low redshift observations are complicated by the fact that the LyC falls in the FUV wavelength range, and currently only the FUV channels on HST have been able to securely get detections.

The recent direct spectroscopic detections of LyC radiation in low redshift galaxies have all been done in nebular line emitting galaxies, many in so called Green peas. These observations have shown that the escape fraction of
ionizing photons is related to (but not necessarily only to) the ionization state of the interstellar medium in the galaxies (through the observed [OIII]/[OII] ratio), the escape fraction of Lyman alpha photons, the shape of the Lyman alpha spectroscopic line profile, and the mix of stellar populations close to the source of ionizing radiation. We recently obtained Lyman alpha imaging with HST of six Green pea galaxies (three with confirmed LyC leakage) in order to study possible correlations of LyC escape with spatial distribution of Lyman alpha emission. I will present results from this study showing an analysis of the spatial extent of Lyman alpha, and comparison of stellar properties, [OIII]/[OII], and Lyman alpha peak separation. We find that the compactness of Lyman alpha emission is anti-correlated with the peak separation (although the sample size is small) indicating that Lyman alpha compactness could be used as a probe of ionizing radiation escape.

54) **Andrea Grazian** (Keynote Presentation)
INAF–Osservatorio Astronomico di Padova, Italy (email: andrea.grazian@inaf.it)

Escaping from the Galactic Labyrinths through stellar Daedalus or following AGN Ariadne's wire like Theseus?

Escaping from the galactic labyrinths is not an easy task, due to the intricate path Lyman Continuum (LyC) photons should travel before ionizing the surrounding IGM/CGM. There are two preferred pathways proposed to escape from the (LyC trapping) Minotaur's Maze: flying easily like Daedalus and Icarus close to the stellar radiation with the risk of a big fallout, or following AGN Ariadne's wire like Theseus, and escaping from the Monster heart towards ionizing freedom. This talk will discuss about possible solutions for this intricate problem, by investigating the LyC escape fraction of bright quasars and faint AGN, especially at high redshift (z>3).

55) **Santosh Harish**
Rochester Institute of Technology (email: harish.santosh@gmail.com)

Evidence for black holes in Green Pea galaxies based on variability and colors

Green Peas (GPs) are a class of low-redshift galaxies with extreme emission lines. They are considered to be the best analogs of high-redshift Lyman-alpha galaxies as well as the strongest known Lyman continuum leakers. In addition, they also contain other high ionization emission lines such as HeII and [NeIII], that indicate the presence of a hard ionizing source. Since GPs are predominantly classified as star-forming, the presence of such high ionization lines begets the question: To what extent are these emission lines powered by star-formation and/or could accretion activity in an active galactic nuclei (AGN) be a significant contributor? In this study, we performed a search for AGN in GPs using observations from the WISE mission and found several GPs indicative of AGN based on mid-infrared colors and variability. Given the recent discoveries by JWST, the physical properties of several high-redshift (z>8) galaxies with strong emission lines are found to be extremely similar to those of GPs. Therefore, GPs are an excellent laboratory for studying the contribution of AGN towards the escape of Lyman radiation and thereby to cosmic reionization. Through this work, we also highlight the importance of employing variability as a diagnostic in selecting AGN candidates that can be optically-hidden, obscured and/or low-luminosity AGN.

56) **Maxime Trebitsch** (Keynote Presentation)
University of Groningen, Netherlands (email: m.trebitsch@rug.nl)

Modelling the contribution of galaxies and AGN to the cosmic reionisation budget

57) **Rogier Windhorst** (Review)
Arizona State University – JWST Interdisciplinary Scientist (email: Rogier.Windhorst@asu.edu)

A Review of Lyman Continuum Radiation with Hubble and the potential of Webb

The hydrogen in the intergalactic medium (IGM) has been reionized since redshifts of about z∼6-7. Yet, the reionizing Lyman Continuum (LyC) radiation has been remarkably hard to find due to ambient hydrogen gas surrounding the reionizing sources. We know those sources exist in the form of hot stars including binaries, and accretion disks around supermassive black holes in Active Galactic Nuclei (AGN). Estimates of the LyC escape fraction (f_esc) have been made from deep ground based spectroscopy above the atmospheric cutoff for objects at z>3, and from space based UV imaging with GALEX and HST, as well as HST spectroscopy, for objects at lower redshifts.

In this talk I will primarily review the LyC work done with HST in the vacuum UV with WFC3 and COS. At redshifts z∼2.3-3, LyC radiation only visibly escapes from a small subset of the objects (i.e., either for a short fraction of their SED life-times, or through a few holes in the ISM), and may on average be somewhat stronger for weak AGN than for faint galaxies, with LyC escape fractions generally <10-30%. Stacked LyC profiles over many objects are also remarkably spotty and non-Sersic like, suggesting isolated lucky paths in the ISM where enough gas has been cleared for LyC to escape.

At redshifts z>3.5, the IGM is opaque enough that direct detection of LyC radiation becomes prohibitive. However, accurate spectral energy distributions of galaxies and weak AGN at higher redshifts can be used to indirectly predict the amount of ionizing radiation that must be present in these objects. Here is where the promise of JWST imaging and spectroscopy comes in to identify such sources of potential ionizing radiation. These include high redshift radio galaxies and AGN (z>4) with evidence for outflows and hot young stellar populations, as well as highly gravitationally lensed star-forming clumps at very high redshifts (z>6) that show evidence for outflows, and young high redshift galaxies with SEDs hot enough to produce LyC and outflow rates high enough to let some LyC escape. While their LyC radiation cannot be observed directly through the IGM, JWST has the potential to provide a plethora of smoking guns that have both the hot SEDs to produce LyC radiation AND the ability to remove their surrounding gas sufficiently to let some LyC escape.

58) **Chris Conselice** (Keynote Presentation)
University of Manchester, UK (email: conselice@gmail.com)

The First Galaxies with JWST and Reionization

I will present work on identifying candidate high-redshift galaxies in the early Universe using the Prime Extragalactic Areas for Reionization and Lensing Science (PEARLS) GTO survey, as well as CEERS, GLASS, NGDEEP, and other public programmes. Our survey covers 100 square arcmins spanning 7 fields to depths greater than m>28.5, from which we have generated the largest JWST selected sample of high-z galaxies to date. I will present the details of this ultra-high redshift sample which contains more than 160 galaxies at z>6.5, including new candidates between 12<z<20. I will discuss our initial findings based on these galaxies, including the rest-frame ultraviolet properties of the sample. Will focus on the evolution of the UV Luminosity Function, as well as the stellar mass function and their contextualised with simulations of the early Universe. Furthermore, I will discuss a new population of low-mass blue galaxies at z > 9 that we recently discovered and overall what our results imply about the causes of reionization and UV radiation leakage from early galaxies.

59) **Jorryt Matthee** (Keynote Presentation)
ETH Zürich, Switzerland (email: mattheej@phys.ethz.ch)

Galaxies as agents of cosmic reionization in the JWST era

Reionization marks the last major phase transition of matter in the Universe and its completion had crucial impact on the formation of the smallest galaxies. While reionization roughly encapsulated the first Gyr of cosmic time, the precise timing, topology and the sources of ionizing photons are unknown. Did reionization proceed rapidly or gradually and was it driven by rare bright galaxies, or numerous faint ones? In my talk I will present the first JWST results from the EIGER survey, which is a large program that is blindly searching for emission-line galaxies in the foreground, vicinity and background of the brightest quasars in the early Universe ($z\sim6$-7). I will show how we confirmed redshifts for >100 galaxies in the first $\sim$500 Myr of cosmic time, and simultaneously measured the mass - metallicity for the first time using efficient NIRCam grism observations. We demonstrate that Lya transmission spikes in the quasar spectrum at $z\sim6$ are detected preferentially at characteristic distances of a few cMpc from galaxies. Finally, I will highlight how to address current limitations in addressing the role of galaxies in reionizing the Universe with new and future VLT programs, and how the MUSE eXtremely Deep Field already provides a glimpse of how we can obtain tomographic studies of (re)ionized bubbles at the end stages of cosmic reionization with future ELT spectroscopy.

60) **Martin M. Roth**
Leibniz-Institut für Astrophysik Potsdam (AIP) and Universität Potsdam (email: (mmroth@aip.de)

A glimpse on future observing facilities with relevance for Lyman escape studies

Over the period of seven years that have passed since the first Kolymbari conference "Escape of Lyman radiation from galactic labyrinths", the exploration of observing facilities such as HST/COS, VLT/MUSE, or, more recently, JWST have been particularly fruitful for the study of Lyman radiation escape — but there are new interesting instruments on the horizon that hold the promise of future progress in the field.

I will present a brief overview with an emphasis on BlueMUSE, and the emerging concept for WST.

61) **Brian Fleming**
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Co-authors: Anne Jaskot, Michael Rutkowski, Stephan McCandliss, Kevin France,
The SPRITE Science Team

The SPRITE Ionizing Radiation Escape Survey (SPIRES)

The SPRITE SmallSat mission has a three-survey science program dedicated to understanding the influence of hot stars on the shaping of galaxies and the circumgalactic medium. One of these surveys, the SPRITE Ionizing Radiation Escape Survey (SPIRES), will expand the breadth of known LyC emitting galaxies by measuring the ionizing spectrum of 50 new targets selected to compliment the existing known sample. SPRITE carries a low resolution (R = 800) far-UV spectrograph with a 100-175 nm bandpass, enabling LyC measurements to a lower redshift than is practical with HST, and will also be the first imaging spectrograph to access the "Lyman UV" (lambda < 115 nm) with its 0.5 degree x 10 arcsecond long-slit. While this imaging capability is driven by the needs of SPRITE's other surveys, it results in a tight spectral extraction height that limits the background subtended in the LyC extraction region. As a result, SPRITE is projected to be the most sensitive instrument to access the Lyman UV to-date. We present an overview of the SPRITE mission, the SPIRES survey, and future plans for data archiving, accessibility, and potential guest observer opportunities. SPRITE is manifested to launch August 30, 2024 from Vandenberg Space Force Base to a 540 km, 83 degree inclination orbit. The SPRITE mission is led by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado and is serving as a testbed for new technologies to help enable Lyman UV sensitivity on the Habitable Worlds Observatory.

62) **Jose M. Vilchez**
IAA-CSIC (email: jvm@iaa.es)
Co-authors: Jorge Iglesias-Paramo, Ignacio del Moral-Castro

A Deep Spectro-photometric Sample of Extreme Emission Line Galaxies with miniJPAS and MUSE HUDF surveys

We have performed a deep search for extreme emission line galaxies (EELG) using the miniJPAS survey (Bonoli+ 2021) and the MUSE HUDF DR2 (Bacon+ 2023). This search has been aimed at extending current samples of EELG and/or Green Pea-like (GP) galaxies towards the lower luminosity, more distant and/or fainter sources domains. Typically, this family of galaxies are expected to present an extraordinary Lyman continuum photon efficiency for its mass, making them ideal laboratories to study the physical conditions of potential candidates for the escape of Lyman photons.
MiniJPAS has observed one square degree on the AEGIS region with the OAJ 2.5m telescope and 56 consecutive narrow band (140 Å FWHM) filters, equivalent to R∼50, covering the entire optical range. The MUSE HUDF survey has recently released its DR2 comprising three distinct areas/depths included in a 3 arcmin x 3 arcmin field observed with the MUSE IFS at VLT. The depth in limiting magnitude/flux reached in these surveys has allowed us to extract sources with ∼22-24 magr (miniJPAS, Iglesias-Paramo+ 2022) or line fluxes ∼3 x 10E-19 erg/s/cm2 (3 sigma, MUSE HUDF. Bacon+ 2023).
A galaxy is selected as EELG/GP when its spectrum present emission line(s) with 300 Å equivalent width or larger. For each JPAS candidate we have a photo-spectrum plus corresponding 56 2D images typically with 1 to 1.5 arcsec spatial resolution; for the MUSE candidates, a spectrum plus a small cutout cube, typically with subarcsec resolution. We have found a total of 17 EELG candidates from miniJPAS, plus 9 candidates showing extreme Halpha/[OIII]/[OII] and 83 extreme Lyalpha from the MUSE HUDF DR2. In this work we present the sample of candidates, the corresponding galaxy images and spectra, as well as the analysis of galaxy morphologies, ionization budget and main physical properties.

63) **Ana Paulino-Afonso**
Institute of Astrophysics and Space Sciences (IA/CAUP) (email: paulinoafonso@astro.up.pt)

FLAEMING: are we able to find SC4K-like LAEs using AI?

Lyman-alpha-emitting galaxies (LAEs) are a diverse population that require large samples to fully understand their nature. Current narrow-band surveys can pre-select thousands of sources for follow-up spectroscopy, but extensive imaging is still necessary to map their evolution over cosmic time. In this talk, we present the FLAEMING project which is a new effort that leverages data-rich surveys such as COSMOS to train machine-learning models for identifying LAE candidates. We have successfully trained a model that can classify LAEs with approximately 90% accuracy using only optical and near-infrared fluxes. Applying our model to the COSMOS field, we predict the existence of around 3,500 new LAE candidates not detected by the SC4K survey, effectively doubling the existing sample. Of these candidates, approximately 100 have been spectroscopically confirmed through public data. We will also discuss why narrow-band surveys might have missed some of these sources and explore the possibility of transferring our model to other large-scale surveys, such as DES or Euclid.

64) **Lorenzo Napolitano**
INAF - OAR and Sapienza - University of Rome (email: lorenzo.napolitano@inaf.it)
Co-authors: L. Pentericci, A. Calabrò

Identifying Lyα emitters by learning from post Reionization-era galaxies in CANDELS survey

For the last 20 years Lyα emission has been one of the major probes of the high redshift universe, shedding light on the Epoch of Reionization. I will present early results of my research which aims at identifying Lyα emitting galaxies using only the information about their morphological and physical properties, (derived from multi-wavelength photometric data) which are known to correlate with the emission of Lyα photons. In this way we can overcome the current limitations in assembling large samples of LAEs from spectroscopic observations and we can make informed predictions that can be used for planning future large scale surveys. The new technique we propose is based on Machine Learning (ML) algorithms which employ ensembles of decision trees, i.e. Random Forest and AdaBoost classifiers. To train and test our algorithm we use a large collection of almost 1500 galaxies with complete photometric and spectroscopic information at $2.5 < z < 4.5$, in the GOODS-South, COSMOS and UDS fields. I will review the most relevant features found in the dataset analysed, report the challenges faced in constructing such a new methodology and the possible applications.

65) **Afonso Manuel Almeida do Vale**
Institute of Astrophysics and Space Sciences (IA/CAUP)/FCUP (email: up201805375@up.pt)
Co-authors: José Fonseca, Andrew Humphrey, Ana Paulino-Afonso

Boosting LAEs identification and characterisation

Finding Lyman emitting galaxies (LAEs) in large numbers usually entails dedicated surveys using custom narrow-band filters. In this talk, we propose to use gradient-boosting algorithms trained using data from the COSMOS2015 catalogue (Laigle et al. 2016) and SC4K (Sobral et al. 2018a) to improve the LAEs' sample sizes. We create balanced datasets with similar redshift and i-band distributions to train the model that better separates similar generic populations. We test several combinations of optical and near-infrared photometric data to find the best possible model to identify LAEs, and we achieve an accuracy of $\sim$80-90%. Aside from selecting new potential candidates (almost doubling the number in the training LAE sample), we also train regression models to get a first approximation of the overall sample properties (Lya redshift, line luminosity and equivalent width). We finally discuss the potential of this kind of model to pre-select potential LAEs of future large-scale surveys.

66) **Bruno Barbosa Cerqueira**

Institute of Astrophysics and Space Sciences (IA/CAUP)/FCUP (email: brunocerqbar@hotmail.com)
Co-authors: José Fonseca, Andrew Humphrey, Ana Paulino-Afonso

Can Deep Learning help us to unveil LAEs through broadband filters?

Detecting LAEs is a costly process that involves specialized observations using various bands, including broad, narrow, and intermediate. With many current and upcoming surveys lacking narrow and intermediate bands and also generating vast amounts of data, the possibility of finding a model based solely on broad band photometry that identifies these emitters is explored. We aim to use a well-calibrated sample of objects, such as SC4K (Sobral et al. 2018), to develop a model using Deep Learning techniques, specifically Convolutional Neural Networks. By balancing data from both with 50% LAEs and 50% non-LAEs, the sources falling within the $2 < z < 6$ range and having an ip_mag_3" value between 22 and 27, and using only three filters (g-, r-, and ip-bands), a satisfactory number of LAE predictions can be achieved with good accuracy 81% for training and 75% for validation. Despite a good accuracy (train: 51%-81% and validation: 54%-75%) considering 1,2,3 and 4 convolutional layers, the model itself was not enough complex, and the best result was with 2 layers. Other Deep Learning architectures, such as ResNet50, Inception, and Xception, were also tested, along with different forms of data input (RGB vs. 3/4-dimensional array input), to improve and generalize the model. The presentation aims to highlight the importance of these techniques in detecting and characterizing LAEs in current and future surveys, thereby aiding the understanding of the mechanisms through which Lyman radiation escapes.

Poster Presentations

1) **Miriam García**

Centro de Astrobiología, CSIC-INTA (email: mgg@cab.inta-csic.es)
Co-authors: M. Cerviño, M. Lorenzo, F. Najarro

Impact of metallicity, mass loss and model parameters on the computed ionizing photons from massive stars

The stellar side of the ionization budget within galaxies must be estimated from stellar atmosphere models. In resolved populations the number of ionizing photons is directly estimated from the best fitting model to each star, while population synthesis codes assign one model to each point of the stellar evolutionary tracks according to their effective temperature (Teff) and luminosity (L). Besides Teff, L and mass, classically considered when generating spectral energy distribution (SED) grids, important factors such as the chemical composition, stellar winds or the extent of the atmospheres may also play a role and need to be carefully accounted for. In this poster we examine these effects and their impact on the ionizing feedback of massive star populations, by using synthetic SEDs computed with FASTWIND and CMFGEN.

2) **Edmund Christian Herenz**

ESO / Leiden Observatory (email: herenz@strw.leidenuniv.nl)
Co-authors: MUSE-GTO Team (TBD)

The faint end of the z>6 Lyman-alpha luminosity function from the MUSE eXtremel Deep Field

The MUSE eXtreme Deep Field provides us with an ideal dataset to assess the faint end of the Lyman-alpha emitter (LAE) luminosity function. To make optimal use of this data we improved the line 3D line detection and cataloguing algorithm used to find LAEs in this data (LSDCat2.0). The improvement does not only increase the signal-to-noise ratios of faint emission lines buried in between the forest of sky-lines, but it also results in a deterministic and easily commutable selection function for the catalogued LAEs. Focusing on LAEs in the highest redshift bin at z>6 we find that 50% completeness limit in Lyα luminosity is $\sim 5\times10^{42}$ erg/s and we detect 10 LAEs with Lyα luminosities $\lesssim10^{42}$ erg/s. We are thus able to provide a first robust blank-field estimate of the "faint-end" of the z>6 LAE LF.

3) **Bodo L. Ziegler**

University of Vienna, Department of Astrophysics (email: bodo.ziegler@univie.ac.at)
Co-author: Polychronis Papaderos

Lyman continuum photon escape in local early-type galaxies

We use integral field spectroscopy data from the CALIFA survey for a spatially resolved study of faint nebular emission in nearly 100 early-type galaxies (ETGs) in the local (<100 Mpc) Universe. A key insight from our study is that the H_alpha luminosity expected from gas photoionization by the evolved (>100 Myr) post-AGB stellar component is by a factor >6 higher than the extinction-corrected observed value. This implies that the major fraction of Lyman-continuum radiation produced by post-AGB stars in the nuclei of ETGs escapes through the tenuous gas of these galaxies without leaving traces of optical line emission. The key consequences of the high Lyman-continuum photon leakage for our understanding of weak-AGN activity in ETGs are briefly highlighted.