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Galaxies in the reionization epoch: the first science case for MOSAIC

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Abstract. One of the principal science goals for the E-ELT is to find the very first galaxies, that probably reionized the universe and probe their physical properties, which may well be very different from those of their lower redshift counterparts, as they are forming from pristine gas, with very low metal abundances. Current results show that the Lyα line coming from young, dust free stellar populations is not only a powerful redshift indicator but its demographics can also be used to constrain the neutral hydrogen fraction at the various epochs, and thus trace the reionization history.
MOSAIC, the Multi-Object spectrograph planned for E-ELT will be able to observe the Lyα emission line in star forming galaxies, up to the very earliest epochs (z$\sim$10). The spectral resolution and high sensitivity of MOSAIC will allow us to probe the warm and hot ionized gas in the interstellar medium of these extremely distant galaxies via studies of the rest-frame UV emission and absorption lines.
MOSAIC will have the combination of capabilities i.e. the required sensitivity, spectral coverage, wide field and multiplex to allow us to reproduce at z $\sim 7-10$, what we can now routinely do at z$\sim 3-5$ with 8-10 m class telescopes.

Key words. Stars: abundances – Galaxies: atmospheres – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances – Cosmology: observations

1. Introduction

The reionization epoch was a key period of the history of the Universe which marked the transition from a neutral intergalactic medium (IGM) to a completely ionized one: understanding when and how this transition occurred and what were the sources that emitted the ultraviolet radiation necessary to ionize the IGM, are amongst the greatest challenges in modern astronomy.

The so called epoch of reionization also saw the birth of the first galaxies which are often identified as sources responsible for the reionizatiion. Observational constraints on the properties of galaxies at z $\geq$ 7 are still scarce, with only a handful of galaxies confirmed at this epoch (e.g. Vanzella et al. 2011, Finkelstein et al. 2013, Pentericci et al. 2014). Due to their extremely faint magnitudes, recent efforts have focused on redshift confirmation, using the rest-frame Lyman-α line and/or the detection of the Lyman break in the stellar continuum caused by absorption by neutral hydrogen in IGM. Little is known about basic properties of the objects detected, such as their stellar masses, their stellar populations or the chemical composition of their interstellar gas (e.g. Jiang et al. 2013).

2. Lyα emission in LBGs as a powerful probe of reionization

The use of Lyα transmission by the intergalactic medium as a probe of its ionization state during the reionization epoch was proposed many years ago (Miralda-Escude & Rees 1998). The Lyα emission which is present in many distant galaxies, is sensitive to even small quantities of neutral hydrogen in the IGM, and it is easily suppressed (Zheng et al. 2010). We thus expect the observed properties of Lyα-emitting galaxies to change at higher redshifts, when the IGM becomes more neutral. A recent approach to study the reionization history of the Universe is to measure the redshift evolution of the Lyα fraction in Lyman-break galaxies (LBGs), i.e., the percentage of LBGs that have an appreciable Lyα emission line (e.g., Stark et al. 2010; Pentericci et al. 2011, LP11; Pentericci et al. 2014, LP14): this fraction is supposed to increase as we move to higher redshift because galaxies are increasingly young and almost dust-free (Bouwens et al. 2014), which facilitates the escape of Lyα photons. On the other hand, this fraction must fall off as we approach the epoch when the IGM becomes significantly neutral.

To study this problem in a systematic and statistically solid way we have designed CANDELSz7, an ESO Large Program to observe 200 galaxies at z$\sim$ 5.8 to 7.3 with FORS2, with integration times that makes us reach very faint EW limits (15 Å for J=25.5 galaxies and 25 Å for J=26.8 galaxies) or a Lyα flux of about 0.5 $\times 10^{-17} erg sec^{-1} cm^{-2}$. Galaxies are selected in the three CANDELS fields visible from Paranal, namely GOODS-South, UDS and COSMOS. The availability of the CANDELS multiwavelength data (e.g. Koekemoer et al. 2011), both from HST and at other facilities means that we can determine the physical properties of the galaxies, such as their stellar masses, dust content, stellar ages and star formation rates, with great accuracy. We can thus disentangle any possible evolution of the intrinsic physical properties from the evolution of the presence of Lyα in the spectra.

Although the program is not completed yet, we have already secured the redshifts of more than 45 galaxies between 5.5 and 7.2. Most of the confirmed galaxies show a clear Lyα line in emission but thanks to our very deep spectra we are able to confirm the redshift of a sizable number of z$\sim$6-6.4 galaxies which show a clear Lyman break with very faint of even absent Lyα (e.g. Figure 1 for some examples of new confirmed targets).

With this much enlarged sample we can place solid constraints on the declining fraction of Lyα emission in z$\sim$7 Lyman-break galaxies compared to z $\sim$6 both for bright and faint galaxies. The decline is very strong especially for faint ($M_{UV} < -21.25$) galaxies. Applying simple models (Dijkstra et al 2014), assuming that the decline is only due to the evolution of the IGM while all other galaxy properties remain unchanged in this redshift interval, and assuming that at z=6 the Universe is completely ionized, a very large change in the fraction of neutral hydrogen is needed to explain the observations ($\sim$ 0.5). Obviously we cannot rule out that an evolution of other properties, and in particular the escape fraction of the Lyman continuum emission come into play and contribute at least partially to the Lyα quenching (e.g. Mesinger et al. 2015).

Recently, the search for primeval galaxies was pushed to even higher redshift using current near-IR MOS facilities: in particular MOSFIRE was able to confirm galaxies showing Lyα out to z greater than 8 (e.g. Zitrin et al. 2015) out of several tens observed. As expected the trend of decreasing Lyα (and thus increasing neutral hydrogen) continues to higher redshift.

Alternative emission lines in the spectra of star forming galaxies of such as CII] at 1908 Å are probing too faint to be considered a valid alternative (e.g. Stark et al. 2015). This means that current 8-10 meter telescope even if used at full power will not be able to secure the redshift of sizable samples of galaxies at z> 7.5 but only a few of the brights ones, or those rare objects showing extreme Lyα emission. To gather large samples (which are also needed e.g. to validate the UV Luminosity function) will have to wait for JWST and E-ELT.

3. MOSAIC a high multiplexing MOS to observe the first galaxies

Since multi-object spectrographs are currently the workhorse instruments of the 8-10 meter class observatories, it is obvious the need for an optical and infrared multi object spectrograph also for the planned 40 meter telescopes. Given that the European ELT 39m telescope, the E-ELT, will have a typical ∼40 $arcmin^2$ patrol FoV, it will provide hundreds of faint targets to be studied spectroscopically. Exploiting these densities efficiently also calls for a MOS relatively early in the E-ELT instrument suite.

The recent ELT-MOS White Paper (Evans et al. 2013 and its revised version Evans et al. 2015) led the MOSAIC consortium to define two main observing modes, i.e., the HighMultiplexMode (HMM) à la OPTIMOS-EVE, with several hundreds mono-aperture fibers with Ground Layer Adaptive Optics (GLAO)/seeing resolution and a High Definition Mode à la EAGLE, with 10 MOAO-fed IFUs with 40-80 mas sampling.

The HMM mode will be dedicated to the study of the integrated (or coarsely resolved with GLAO) light emitted by the most compact sources such as the very first galaxies in the reionization epoch; the HDM will be necessary to spatially-resolve the properties of, e.g., distant star forming galaxies with high enough signal to noise.

Obviously one of the initial science cases for MOSAIC will be the search and study of the primeval galaxies via Lyα emission, Lyman break in the continuum and UV absorption lines as discussed extensively in Evans et al. 2015.

3.1. *Simulation of MOSAIC observations of Lyα and UV absorption in high z galaxies*

We simulated the detection of UV interstellar lines at z = 7 and the detection of the Lyman α line and the Lyman break at z = 9, both assuming MOAO-assisted IFUs and GLAO-fed fibers. The simulations are performed with a scientific simulator that was developed in the context of the E-ELT phase A studies (M. Puech et al. 2010). The properties of the galaxies are modeled as those found mostly from the CANDELS survey: the typical sizes (half light radii) are scaled with their absolute magnitude as found for example by Grazian et al (2012). The fluxes and shapes of the Lyα emission line are also scaled according to what is observed at high redshift: in particular we assume a truncated Gaussian profile for the Lyα line with a a FWHM of 150-500 km/s and a correlation of the Lyα EW with magnitude in the sense that faint galaxies have on average larger EWs as routinely observed at z=3-7 (e.g. Stark et al. 2011).

Using the above parameters simulations are run with varying pixel size and the signal to noise achieved is recorded. The most constraining case is the detection of UV interstellar lines, since in this case we need to achieve a very high signal to noise in the continuum: the optimal pixel size is found to be 80 mas, which allows detecting UV lines up to $J_{AB} \sim 27$ in 40 hours of integration time. Lyman Alpha Emitters and Lyman Break Galaxies are detected respectively up to $J_{AB} \sim 30$ and $J_{AB} \sim 28$ with a 80 mas/pixel IFU and within only 10 hours of integration time.

Detection limits are typically 0.5-1 mag fainter using MOAO-fed IFUs than using GLAO-fed fibers, but the multiplex is one magnitude larger in the mode using GLAO-fed fibers. For full details of the simulation see Disseau et al.2014, and Puech et al. 2013.

4. Conclusions

The search for primeval galaxies and the exploration of the reionization epoch are the current key issues for extragalactic astronomy. The space density of these faint targets requires the next generation of telescope to be equipped with a multi objects spectrograph facility . MOSAIC will offer both a high multiplexing mode with a large number of mono

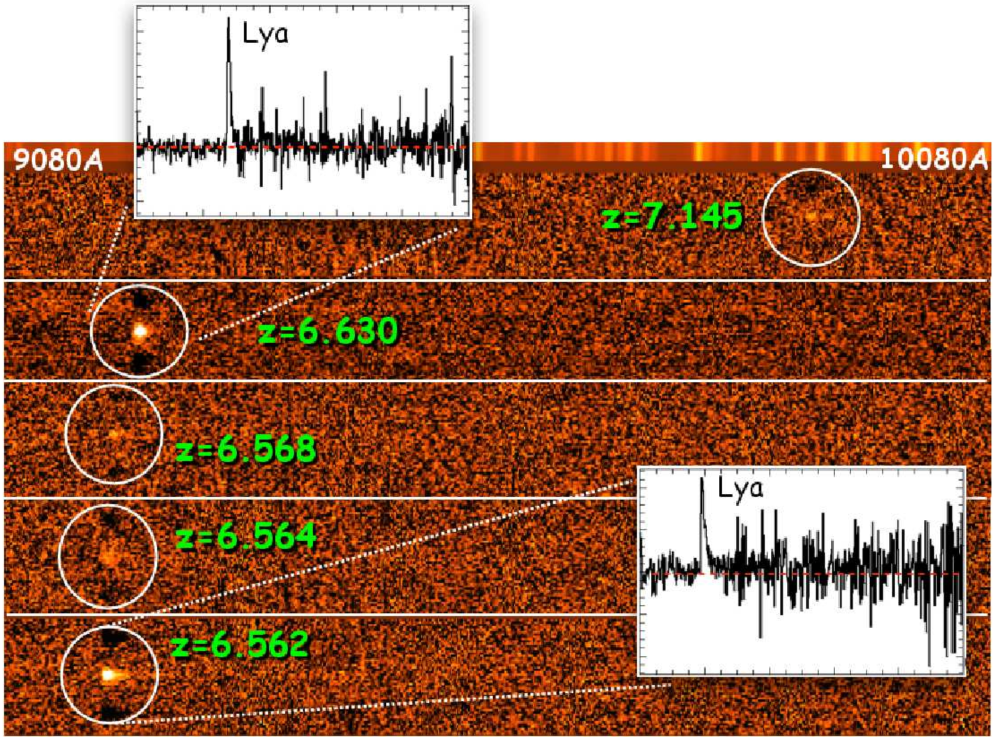

Fig. 1. The spectra of some of the new galaxies confirmed by our ESO Large Program CANDELSz7 (Pentericci et al. in preparation). Most confirmed galaxies show a bright Lyα in emission as the only signature in the spectrum. When the signal to noise is sufficiently high, the line shows the typical asymmetry.

apertures fibers to observe large numbers of galaxies and a high definition model with 10 MOAO IFUS for detailed studies of the brightest objects, thus providing the most complete view of the evolution of galaxies in the early universe.

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