Challenges in Panchromatic Modelling with Next Generation Facilities
Proceedings IAU Symposium No. 341, 2018
M. Boquien, E. Lusso, C. Gruppioni & P. Tissera, eds.

doi:10.1017/S1743921319004721

Modeling galaxy evolution at high-redshift in highly overdense and normal regions

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Abstract. We present results from high-resolution, zoom-in cosmological simulations to study the effect of feedback from galactic outflows on the physical and Lyα properties of high-redshift galaxies in highly overdense and normal environments at $z \gtrsim 6$. The Lyα properties have been obtained by post-processing the simulations with a Monte-Carlo radiative transfer (RT) code. Our results demonstrate that galactic outflows play an important role in regulating the growth of massive galaxies in overdense regions as well as the temperature and metallicity of the intergalactic medium. In particular, we find that galactic outflows are necessary to reproduce the observed Lyα luminosity functions as well as the apparent Lyα luminosity, line width and equivalent width distributions of luminous Lyα emitters at $z \sim 6$.

Keywords. cosmology: theory, galaxies: formation, galaxies: evolution, galaxies: high-redshift, methods: numerical, radiative transfer

1. Introduction

Massive high-z galaxies are found preferentially in rare, overdense regions of the universe. In dense environments, galaxy evolution is expected to proceed more rapidly than in average fields, with elevated gas accretion and star formation rates (SFRs) that can power strong galactic outflows (Romano-Díaz *et al.* 2011, 2014). Understanding the dependence of galaxy formation on environment is thus crucial for interpreting observations at high-z. An increasingly large number of high-z galaxies have been detected as Lyα Emitters (LAEs, Ouchi *et al.* 2018). Because Lyα photons interact strongly with HI, LAEs constitute a promising probe of the ionization state of the intergalactic medium (IGM) in the late stages of the reionization era at $z \gtrsim 6$. However, due to the resonant scattering nature of the interaction, extracting constraints on reionization from apparent Lyα properties of LAEs is challenging and requires detailed modeling of the Lyα line and its transfer through the IGM (Dijkstra 2014; Sadoun *et al.* 2017).

We have performed high-resolution, cosmological zoom-in simulations to study galaxy evolution in highly overdense and normal regions at $z \sim 6 - 12$ (Sadoun *et al.* 2016). Various galactic feedback models were implemented in order to investigate the effects of galactic outflows on the physical and Lyα properties of galaxies. We have obtained the apparent Lyα properties of galaxies by post-processing the output of the simulations with a 3-dimensional Monte-Carlo Lyα radiative transfer code (Sadoun *et al.* 2018).

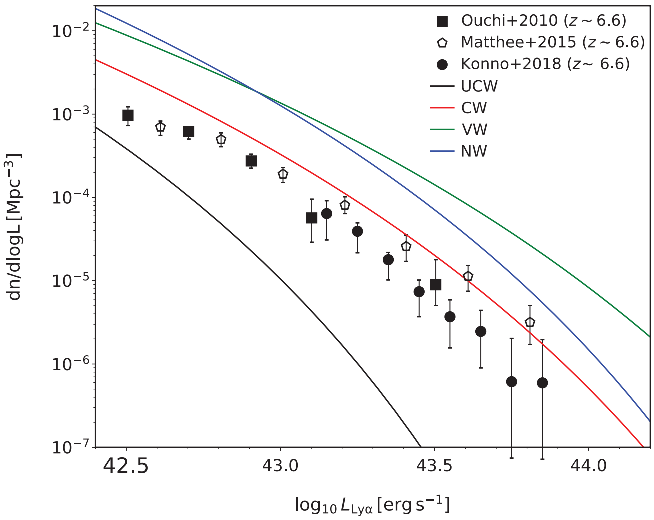

Figure 1. Comparison between the Lyα luminosity functions (LFs) in the unconstrained (UCW) and constrained (CW, VW and NW) simulation runs with observational data. The Lyα LFs are obtained by convolving the $L_{\rm Ly\alpha}$-$M_{\rm h}$ relation predicted by our radiative transfer calculations with the theoretical halo MF.

2. Numerical methods

We use the hydro+N-body code PGADGET-3, with both constrained (CR) and unconstrained (UCR) initial conditions. The CR runs contain the seed of a DM halo of $10^{12}\,h^{-1}\,{\rm M}_{\odot}$ that should collapse by $z \sim 6$. The UCR runs represent the parent realization of its constrained counterpart. The simulations include cooling, SF, stellar and SNe feedback. The CR suite has been run with three different prescriptions for galactic winds: constant velocity wind (CW), variable velocity wind (VW), and no-wind (NW) models. The UCR have been run with CW and VW models.

Both the ionization state of the gas and the Lyα radiative transfer (RT) were calculated *a posteriori* on a grid constructed from interpolating the SPH data obtained from the simulation outputs at $z \sim 6.6$. The former was computed with self-shielding of dense gas taken into account, assuming photoionization by a uniform UV background and by the local ionizing flux produced by galaxies in the simulation. The Lyα RT was performed using the Monte-Carlo radiative transfer code from Zheng & Miralda-Escudé (2002).

3. Results

We find that the Lyα properties of massive galaxies in the overdense region match well recent observations of luminous LAEs at $z \sim 6-7$, in terms of apparent Lyα luminosity ($L_{\rm Ly\alpha}$), line width and Lyα equivalent width distributions. Without winds, these galaxies appear less Lyα bright due to differences in the line profile emerging from galaxies (which depends on the SFR and outflow velocity) and, in the distributions of neutral gas in the IGM. The $L_{\rm Ly\alpha}$-halo mass ($M_{\rm h}$) relation appears sensitive to the environment and the wind model, in contrast to $L_{\rm Ly\alpha}$-stellar mass or SFR relations. The Lyα LFs constructed from convolving the $L_{\rm Ly\alpha}$-$M_{\rm h}$ relation with the theoretical halo mass function (MF) reproduce reasonable well the observed one at $z \sim 6.6$ (Fig. 1). Our results are consistent with a patchy reionization scenario in which observed luminous LAEs at $z \gtrsim 6$ are found preferentially in ionized, overdense regions.

https://doi.org/10.1017/S1743921319004721 Published online by Cambridge University Press

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