# Semi-analytical modelling of Lyman-alpha Emitters


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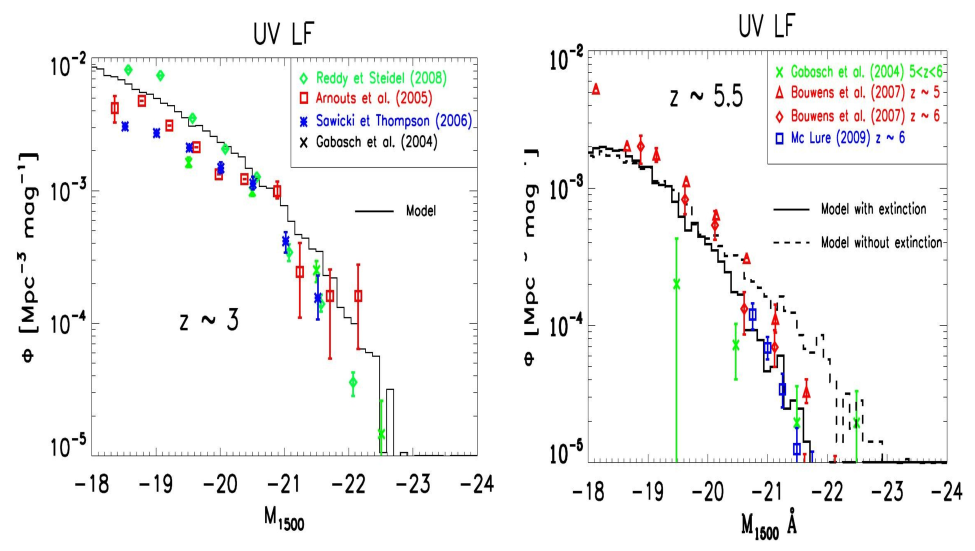
**Abstract.** We present a semi-analytical model to explain lyman-alpha emission in high redshift (3 < z < 6) star-forming galaxies following a statistical approach. The GalICS hybrid model (Hatton et al., 2003), coupling cosmological simulations and semi-analytical recipes to describe dark matter and baryonic matter, is used to predict physical properties of galaxies. UV luminosity functions at z=3 and 6 are reproduced. GalICS is furthermore coupled in post-processing with a grid of models made with the 3D Lya radiation transfer code MCLya (Verhamme et al., 2006). This RT code calculates the escape fraction of lyman-alpha photons through a homogeneous expanding shell of neutral hydrogen and dust. We compute the distributions of lyman-alpha escape fractions for GalICS star-forming galaxies. Then, we are able to build the lyman-alpha luminosity functions at z=3 and 6 and find a good agreement with the available data. This model is therefore intended to make predictions for forthcoming instruments, such as MUSE and Nirspec, which will provide better insight and larger data samples in the study of high redshift galaxies.


**GalICS.** The hierarchical galaxy formation model GalICS (Hatton et al.,2003) combines N-body cosmological simulations to describe dark matter and semi-analytical prescriptions for baryonic matter.
Here, we use a N-body simulation describing a volume of $(100h_{100}^{-1}\,Mpc)^3$ with $512^3$ particles, and assuming a WMAP-3 cosmology ($\sigma_8=0{,}77$, $\Omega_m=0{,}24$, $\Omega_\Lambda=0{,}76$).

The version of GalICS we used here has been updated to account for cold gas accretion and was fit to high redshift UV luminosity functions (LF) (see figure).

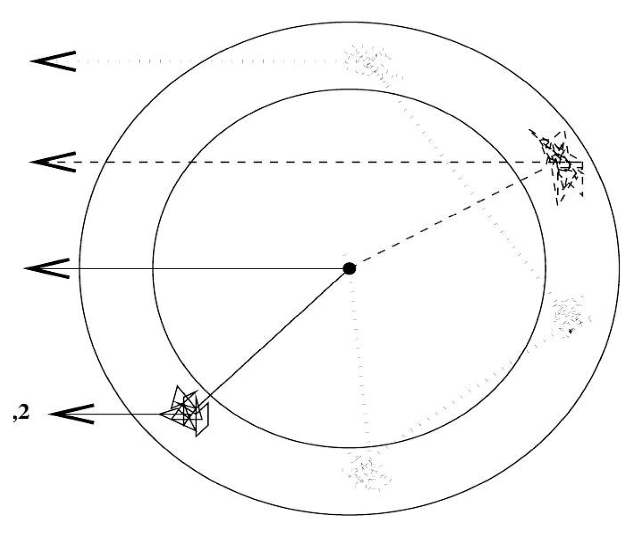
As an output, GalICS predicts a set of physical properties for all galaxies in the simulated volume (e.g. stellar & gas masses, SFR, metallicity...). We use these predictions as an input for our Lyα model.




**MCLya.** The 3D radiative transfer code MCLya (Verhamme et al., 2006) computes Lyα photons transfer through a moving medium. It uses Monte Carlo techniques and a Cartesian grid. We use this to run a series of expanding shell models described by four parameters:

- expansion velocity $V_{exp}$
- column density $N_H$
- dust opacity $\tau_{dust}$
- thermal velocity in the shell *b*

*This library contains more than 5000 configurations with $V_{exp}$ varying from 0 to 500km/s, $N_H$ from $10^{16}$ to $5.10^{21}\,cm^{-2}$, $\tau_{dust}$ from 0 to 4 and b from 10 to 160 km/s.*
*Each model comes with a different spectrum and Lyα line.*



**Coupling.** We develop a simple wind model in order to predict, for GalICS galaxies, the values of the input parameters of the MCLya grid.

- We take the velocity of the shell as the escape velocity $V_{exp}=\sqrt{\frac{2GM}{R}}$ where *M* and *R* are the mass and the radius of the galaxy, respectively.

- For the column density, we let a fraction of the gas present in the ISM of the galaxy to be swept in the shell

$$N_H=\epsilon\frac{M_{gas}^{cold}}{4\pi\mu m_H R^2}$$

where ε, the only free parameter of our model, is the fraction of gas ejected into the shell, μ the mean particle mass in a fully neutral gas, $m_H$ the hydrogen atom mass and $M_{gas}^{cold}$ the mass of neutral hydrogen present in the ISM.

- For the dust optical depth, we follow *Guiderdoni et al.* (1987) and write

$$\tau_{dust}=\left(\frac{A_\lambda}{A_V}\right)\left(\frac{Z}{Z_\odot}\right)^s\left(\frac{N_H}{2{,}1\times10^{21}\,cm^{-2}}\right)$$

where Z is the gas metallicity, $A_\lambda / A_V$=3,43 is the extinction curve for solar metallicity at the Lyα wavelength 1216 A.

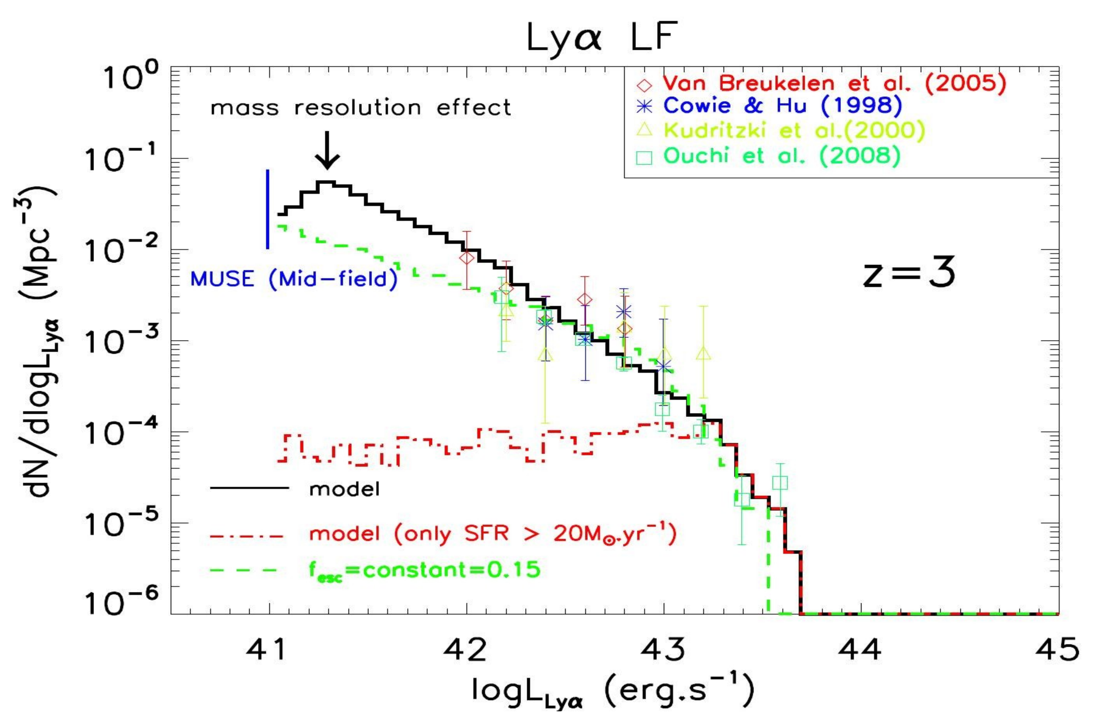
- We decide to set the thermal/turbulent velocity in the shell *b* to 20 km/s, corresponding to a typical temperature value $10^4\,K$.

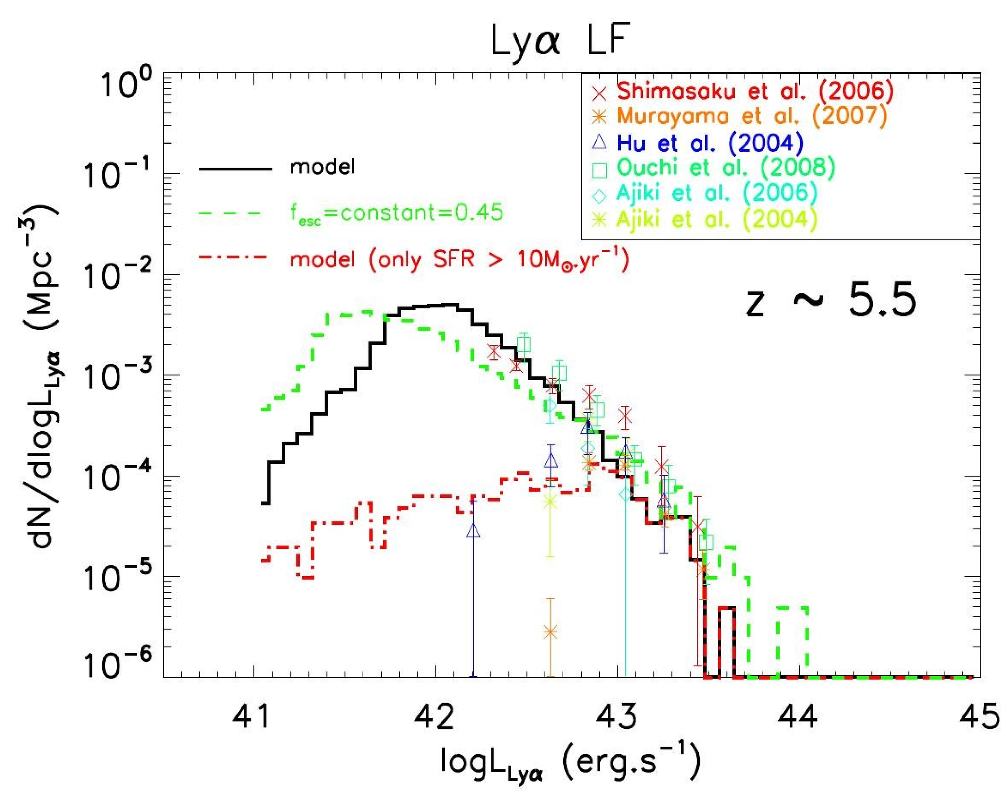
Matching the values obtained by this model for GalICS galaxies with the available input parameters of the MCLya grid, one can calculate Lyα escape fractions *fesc* and compute Lyα spectra.

## Results.

To compute the Lyα luminosity for GalICS galaxies,

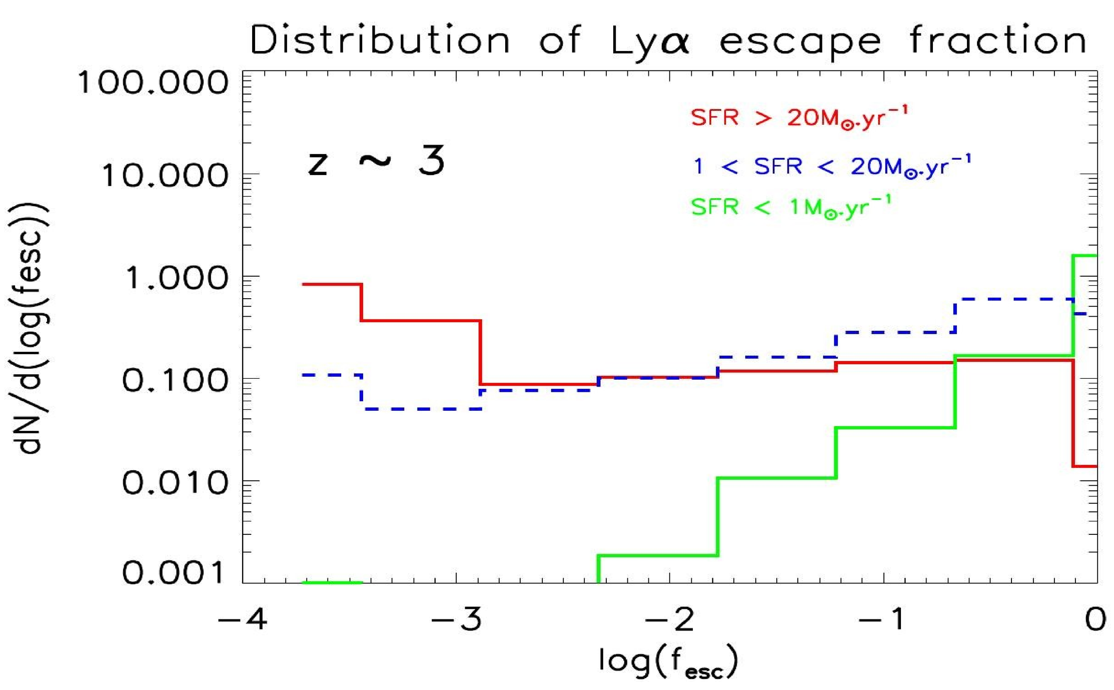
we use $L_{ly\alpha}^{intr}(erg.s^{-1})=10^{42}\left(\frac{SFR}{M_\odot yr^{-1}}\right)$ to calculate the intrinsic luminosity. Then, by multiplying this by the Lyα escape fraction *fesc* for each galaxy, we are able to build the Lyα LFs. We fit the data at z ~ 3 (and 5.5) by setting the free parameter ϵ to 0,6 (0,06).
We notice that the model curve at the faint end is steeper than the one computed with a constant *fesc* for all galaxies.
Intensely star-forming galaxies $(SFR>20\,M_\odot.\,yr^{-1})$ are responsible for the bright end $(L_{ly\alpha}>10^{43}\,erg.s^{-1})$.

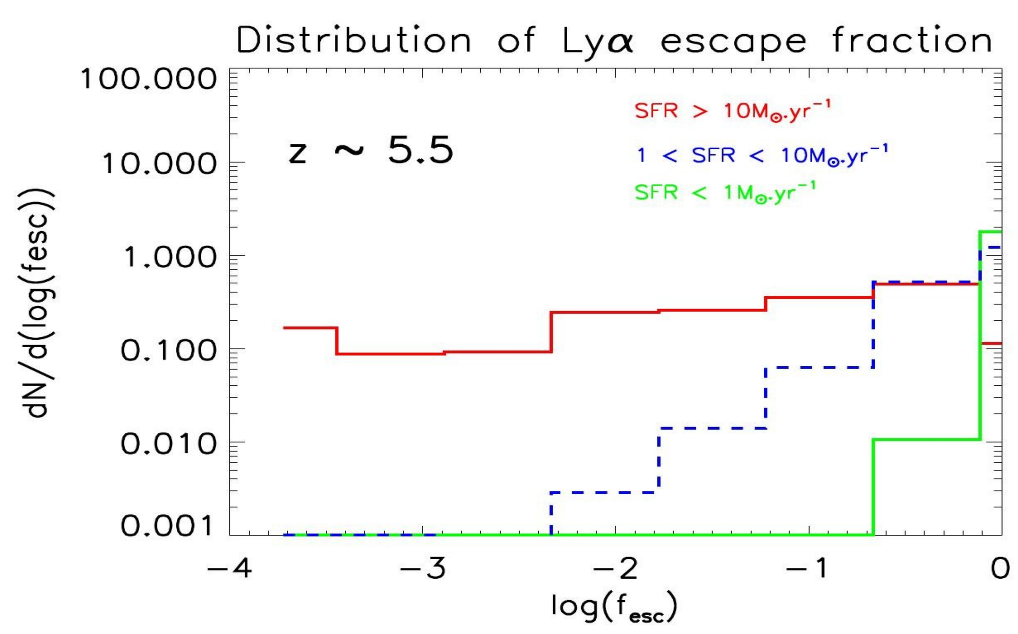


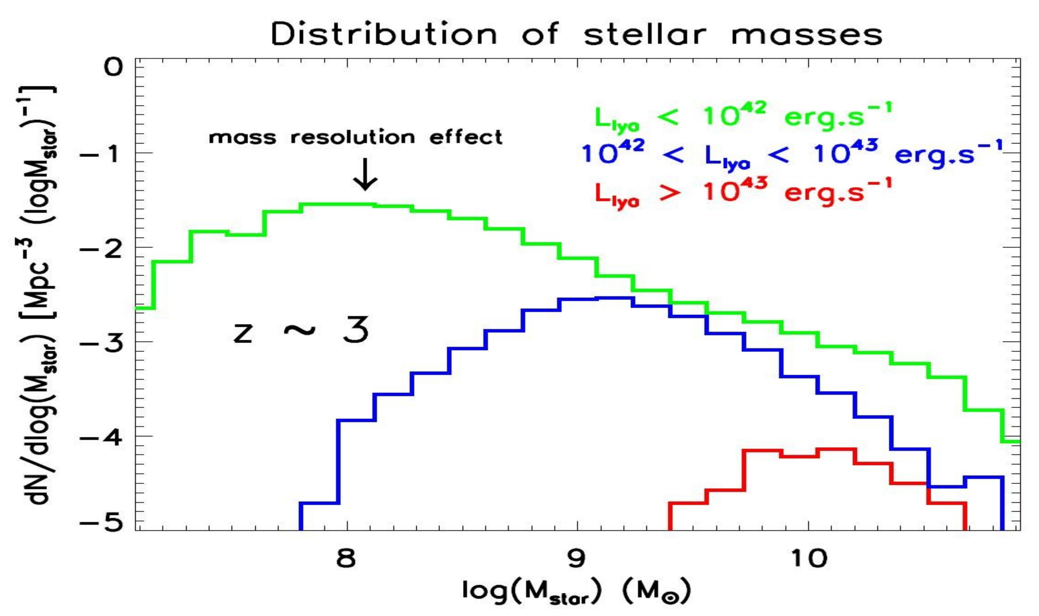

The distribution of Lyα escape fractions is plotted for several galaxy's SFR ranges. High-SFR galaxies have a nearly constant *fesc* distribution from 0 to 1whereas lower SFR objects show higher *fesc* with a maximum value of 1.

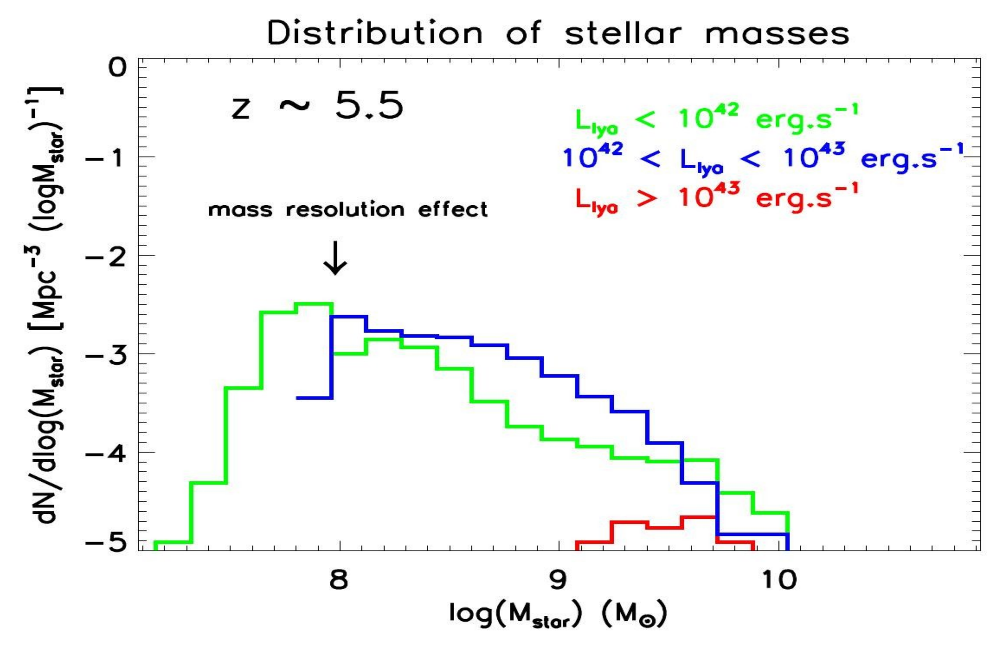
Then, in this model, low-SFR galaxies making the faint end of Lyα LF at both z~3 and 5,5 tend to let almost all the Lyα photons escape. High-SFR objects contribute equally to all luminosities.




We find out that higher Lyα luminosity galaxies have higher stellar masses at both z ~ 3 and 5,5. Nevertheless, the high stellar mass end is dominated by low Lyα luminosity galaxies.
Galaxies with $L_{ly\alpha}>10^{42}\,erg.s^{-1}$ (corresponding to the current data) have stellar masses at z~3 (5,5) ranging from $6.10^7$ to $10^{11}\,M_\odot(6.10^7$ to $10^{10}\,M_\odot)$. Mass resolution limit might lead us to underpredict the number of low stellar mass galaxies.




**Conclusion.** We have made a coupling of the hierarchical galaxy formation model GalICS and the Lyα radiative transfer code MCLya. Our model is able to fit UV and Lyα LF data at high redshift and to make predictions for Lyα emitting galaxies to be observed by MUSE. It shows significant difference with a constant Lyα escape fraction model at both z~3 and 5,5 as it predicts a larger number of faint Lyα emitters. Physical properties, such as stellar masses, of those objects can, as well, be evaluated.


References:

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