Radiative Transfer Modeling of Lyman Alpha Emitters

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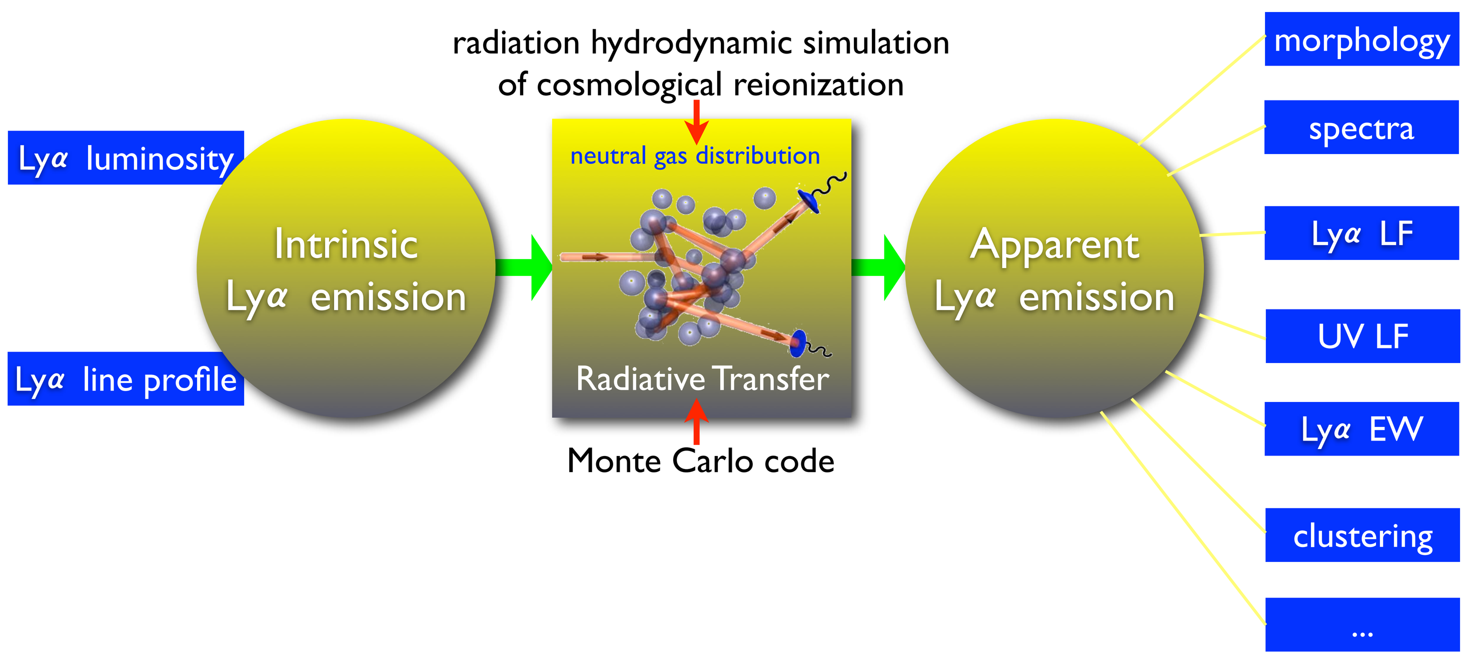
We model z=5.7 Lyman Alpha Emitters (LAEs) by combining a state-of-the-art cosmological reionization simulation (Trac, Cen, & Loeb 2008) in a box of $(100\mathrm{Mpc/h})^3$ with a Monte Carlo Lyα radiative transfer code (Zheng & Miralda-Escudé 2002).

Model Summary:

Radiative transfer in the circumgalactic and intergalactic environment (provided by the cosmological reionization simulation) is assumed to be the major factor in transforming the intrinsic Lyα emission to the observed emission.

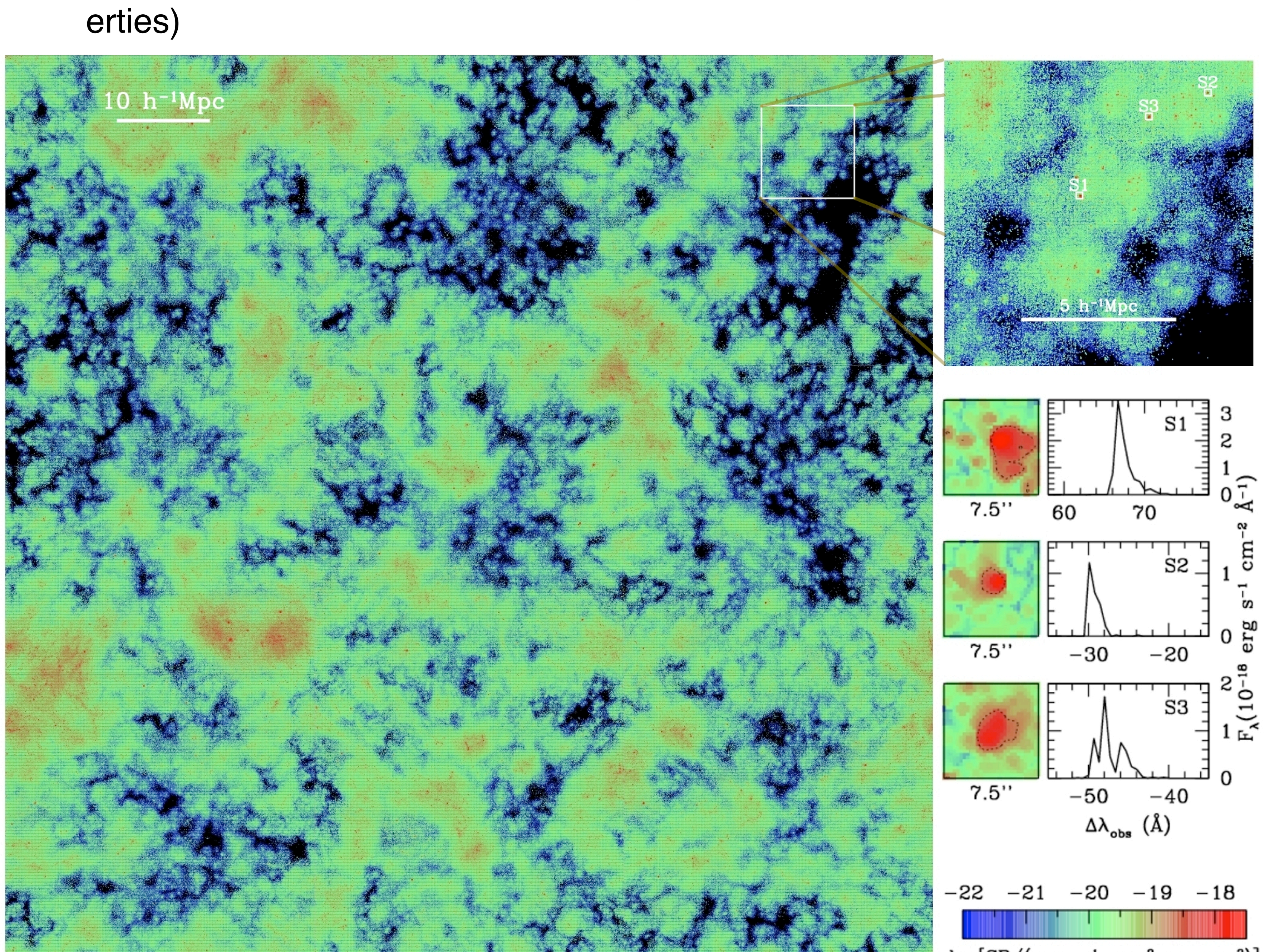


Model Setups:

- Each LAE is located at the center of a dark matter halo.
- Lyα photons are initially emitted from a point source.
- Lyα luminosity is proportional to star formation rate.
- The initial Lyα spectrum follows a Gaussian profile with width determined by halo virial temperature.

Model Outputs:

- Lyα (narrow-band) image and spectra
- LAEs identified from the image following typical observational procedures
- observational properties of LAEs (e.g., luminosity functions, clustering properties)



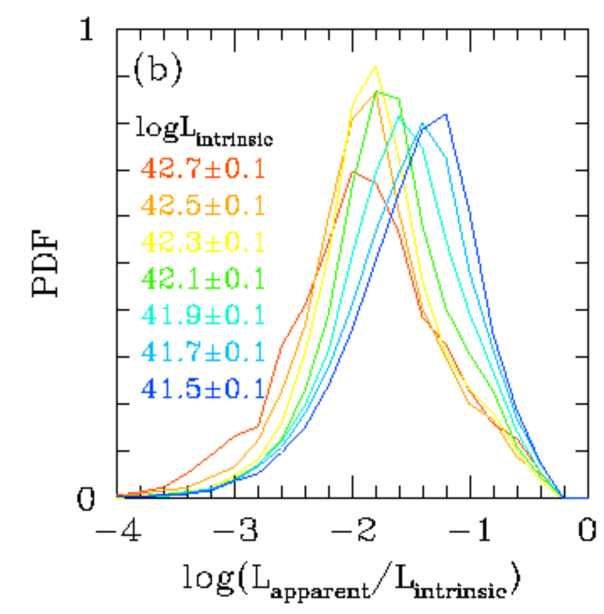
Top: Lyα image and examples of LAEs and the extracted spectra from the model. The area and depth shown in this plot correspond to those of the Subaru /XMM-Newton Deep Survey for z=5.7 LAEs (Ouchi et al. 2008).

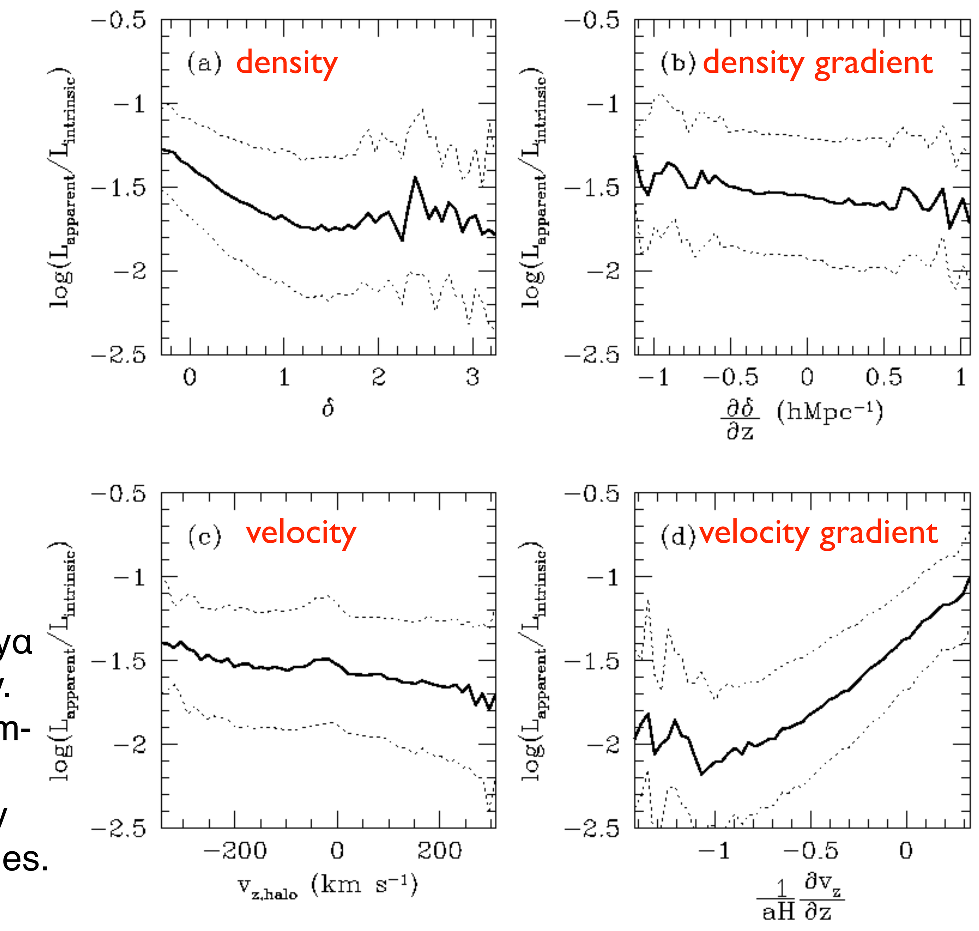
Main Results:

- Radiative transfer (resonant scattering) in the circumgalactic and intergalactic media leads to both spatial and frequency diffusion of Lyα photons.
- The Lyα emission from high-redshift starforming galaxies becomes extended and usually only the central, high surface brightness region can be observed.
- Radiative transfer leads to strong coupling between the observed Lyα emission and circumgalactic and intergalactic environment (density and velocity structures).
- At fixed intrinsic Lyα luminosity, the observed (apparent) Lyα luminosity has a broad distribution, reflecting the broad distribution of environment.

References:

- Ouchi, M., et al. 2008, ApJS, 176, 301
- Steidel, C.C., et al., 2011, ApJ, arXiv:1101.2204
- Trac, H., Cen, R., & Loeb, A. 2008, ApJ, 689, L81
- Zheng, Z., & Miralda-Escudé, J. 2002, ApJ, 578, 33
- Zheng, Z., Cen, R., Trac, H., & Miralda-Escudé, J. 2010, ApJ, 716, 574
- Zheng, Z., Cen, R., Trac, H., & Miralda-Escudé, J. 2011a, ApJ, 726, 38
- Zheng, Z., Cen, R., Weinberg, D. H., Trac, H., & Miralda-Escudé, J. 2011b, ApJ, arXiv:1010.3017

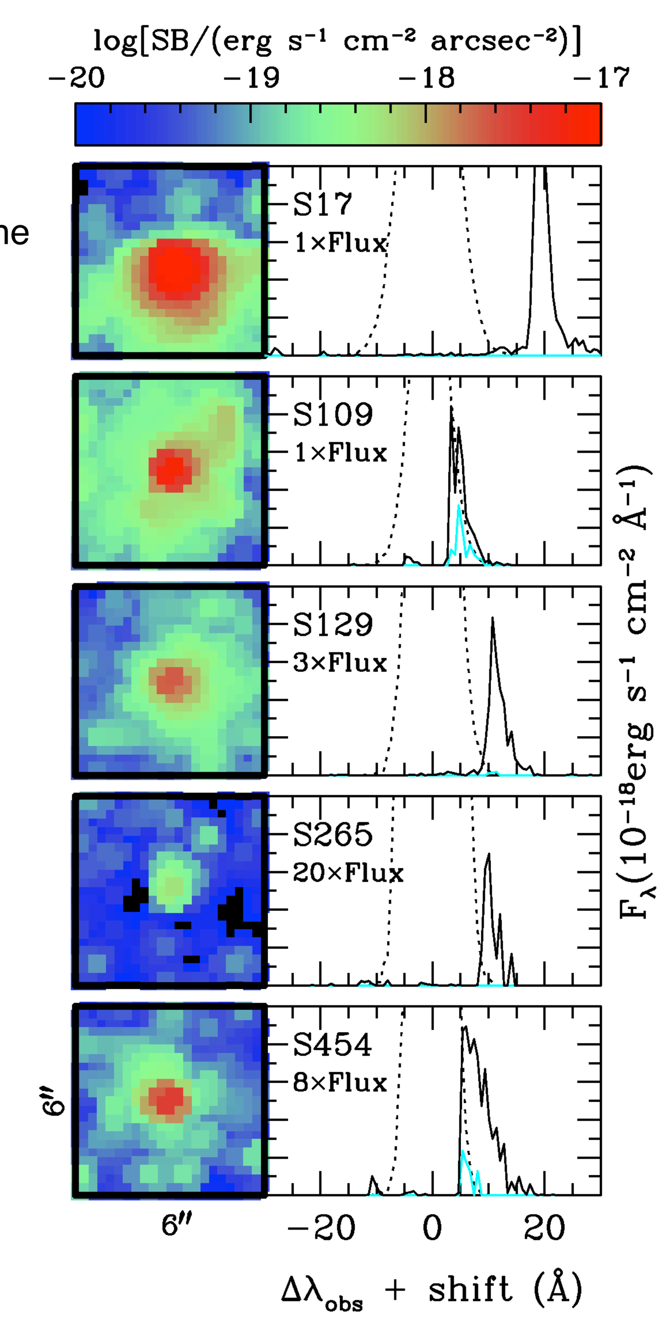


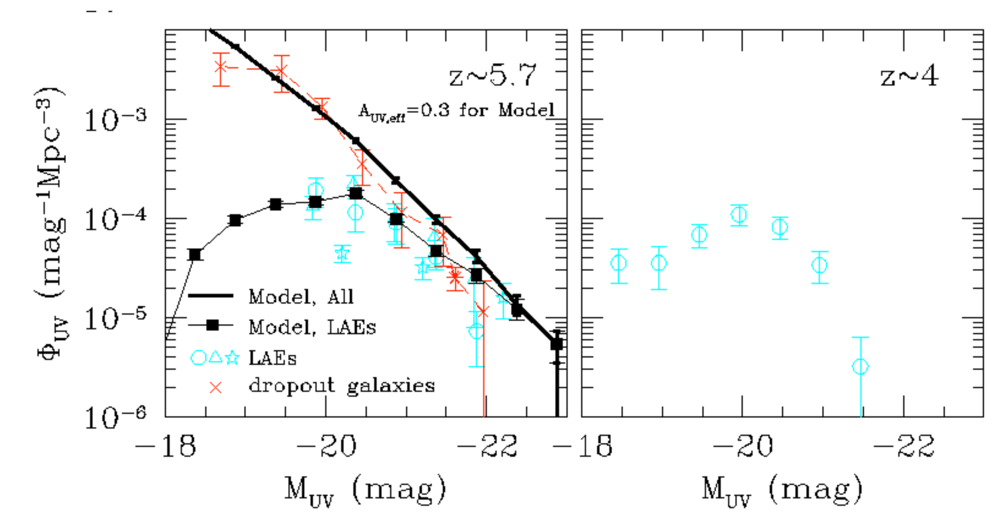


Top: The distribution of observed (apparent) Lyα luminosity at each fixed intrinsic Lyα luminosity. The broad distribution reflects that of the circumgalactic and intergalactic environment.
Right: The observed-to-intrinsic Lyα luminosity ratio as a function of key environmental variables.

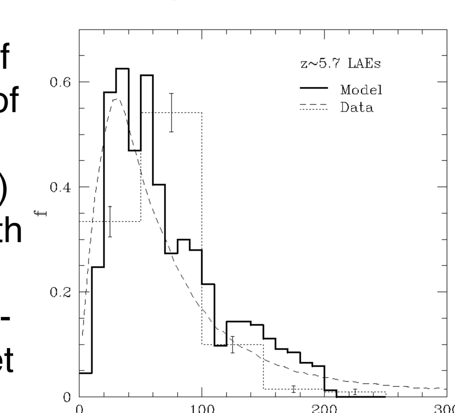
Highlight I: The simple model is able to provide natural explanations for an array of observed properties of LAEs.

Right: Images and spectra for a few LAEs in the model, which are similar to those of observed LAEs. Dotted curves are the intrinsic spectra. Black solid curves are the spectra after a full Lyα radiative transfer. Cyan solid curves are spectra with a simple treatment of the radiative transfer, which modifies the intrinsic spectra by $\exp(-\tau_\nu)$.



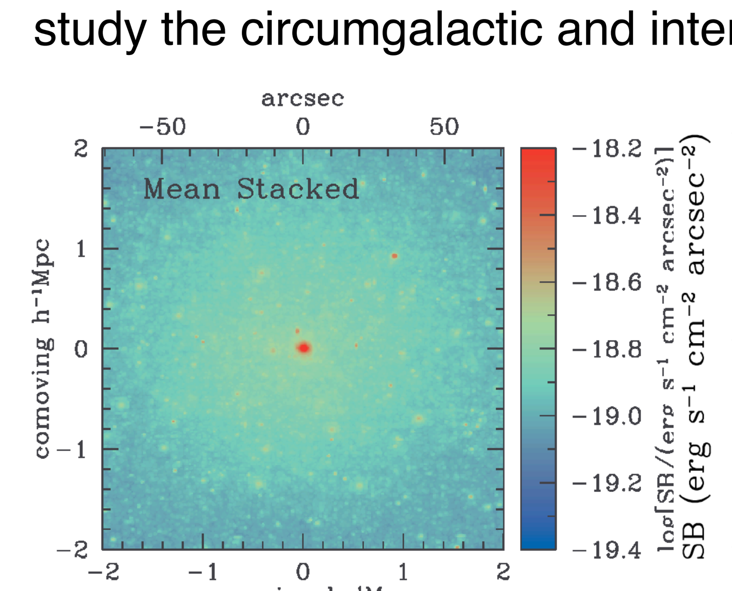


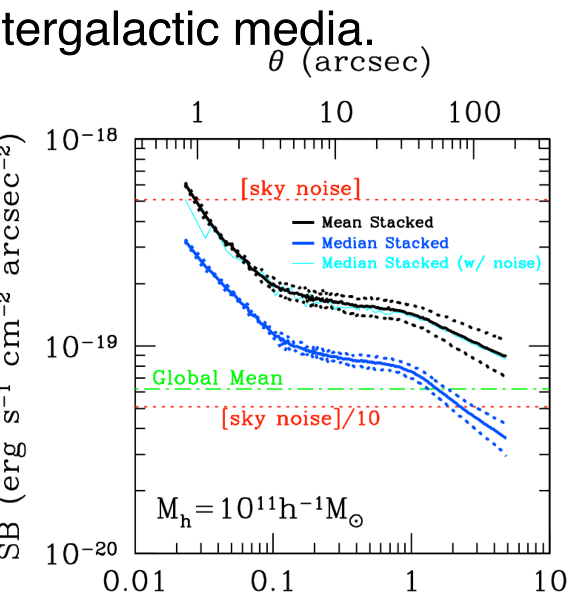
Top: The model explains the shape of the observed UV luminosity function of LAEs.
Right: The Lyα equivalent width (EW) distribution from the model agrees with the observation. The EW distribution reflects environment dependent radiative transfer of Lyα photons. (Zheng et al. 2010)



Highlight II: The model predicts extended Lyα emission around high-redshift starforming galaxies (LBGs or LAEs).

The prediction (Zheng et al. 2011b) starts to be verified or tested by latest observations (e.g., Steidel et al. 2011). The extended emission opens a new window to study the circumgalactic and intergalactic media.

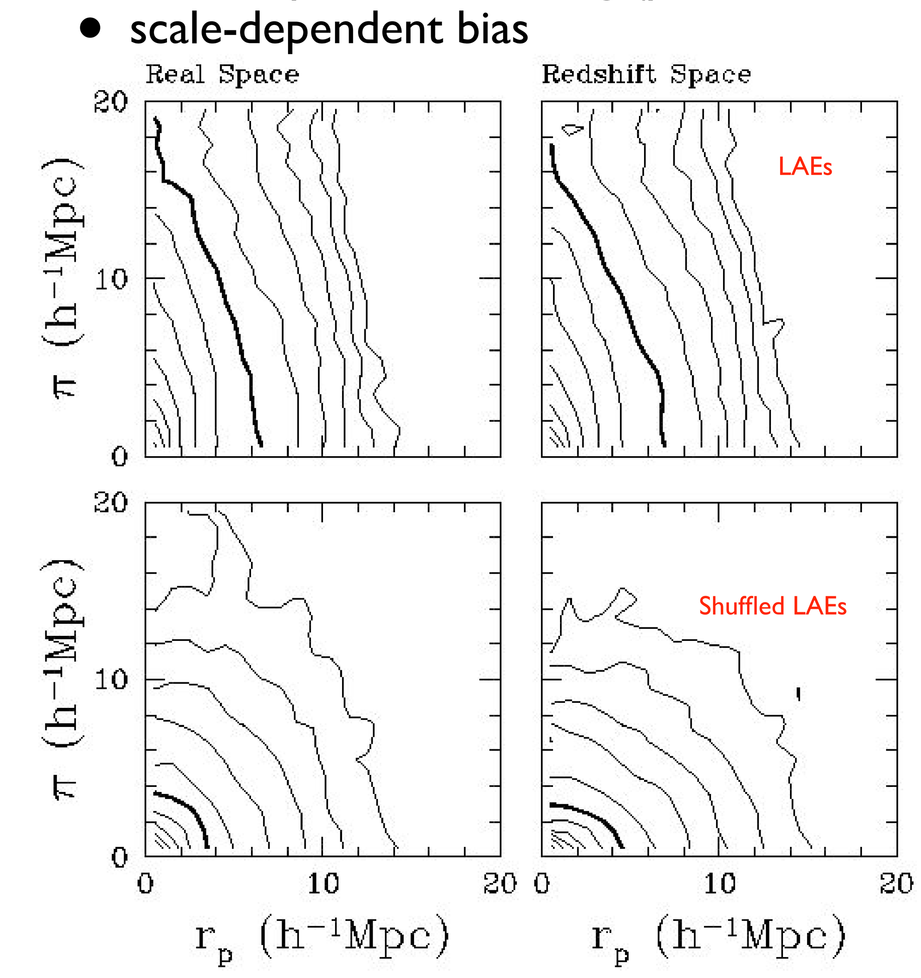




Left: The stacked narrowband Lyα image and surface brightness profile for high-redshift starforming galaxies in halos of mass 10^{11}Msun/h. The stacking suppresses the sky noise and can reveal the faint extended Lyα emission around these galaxies. At large radii, clustered sources start to contribute, leading to interesting features in the surface brightness profile. (Zheng et al. 2011b)

Highlight III: The model predicts new effects in the clustering of LAEs caused by environment dependent Lyα radiative transfer.

- enhancement (suppression) in the transverse (line-of-sight) fluctuation
- anisotropic 3D clustering (prominent elongation along the line of sight)
- scale-dependent bias



Left: The top panels show the model prediction of the 3D two-point correlation functions for a sample of luminosity-threshold LAEs in real and redshift space, respectively, while the bottom panels shows those for a control sample called shuffled-LAEs, which is constructed by eliminating the environment dependent Lyα radiative transfer effect. Radiative transfer of Lyα photons imposes a selection effect for LAEs - LAEs in certain (density and velocity) environments are easier to be detected. Such a selection effect causes anisotropic spatial distribution of LAEs and a prominent elongation feature along the line-of-sight in the 3D two-point correlation function. The Lyα selection effect is a real space effect. It is opposite to and stronger than the linear redshift distortion (Kaiser effect). It shows up on much larger scales than the Fingers-of-God effect. (Zheng et al. 2011a)