Semi-analytic modelling of high-redshift Lyman-alpha galaxies

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SURFS workshop
Perth, March 2013

Introduction - *Lyα emission & transfer*

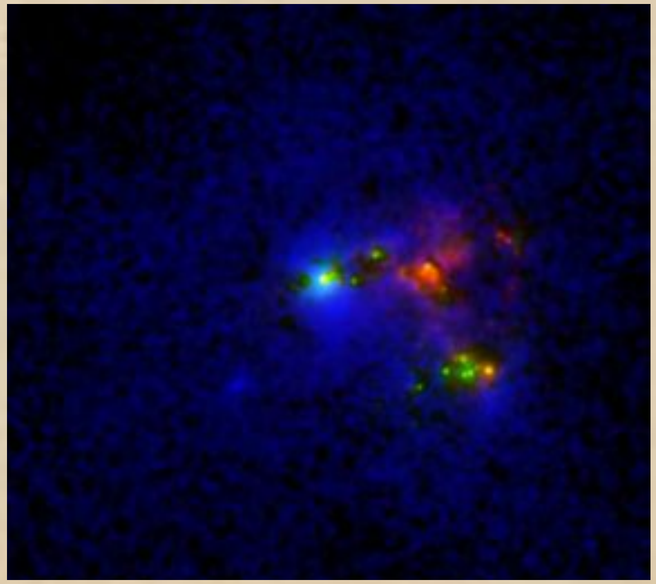
Lyα emission from star-forming regions

- Most intense line (up to ~10% L_{bol})
- $\mathbf{L}_{\mathrm{Ly}\alpha}^{\mathrm{intr}} \propto \frac{\mathbf{2}}{\mathbf{3}}\dot{\mathcal{N}}_{\mathrm{ion}}^{\mathrm{OB}} \propto \mathrm{SFR}$
- Can probe high-z galaxies, especially faint ones undetected in UV-continuum

ISM optically thick for Lyα (τ_{HI} **> 1**) => **resonant scattering**

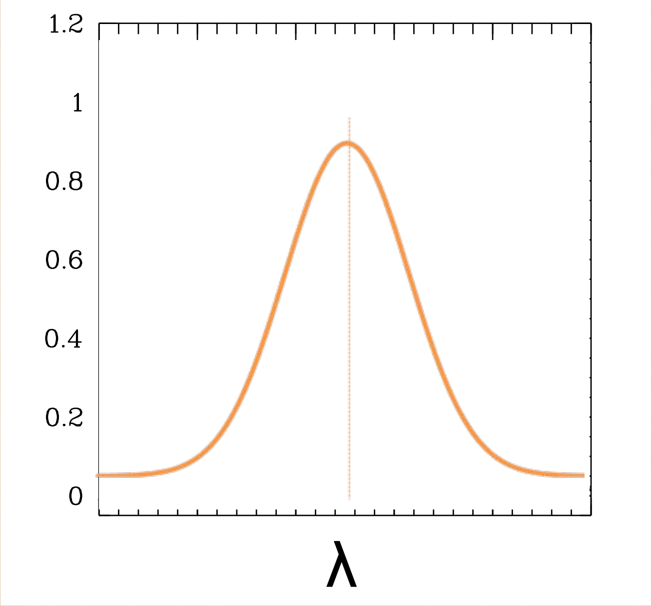
in real space

Lyα
Hα



Ostlin+09

in frequency space



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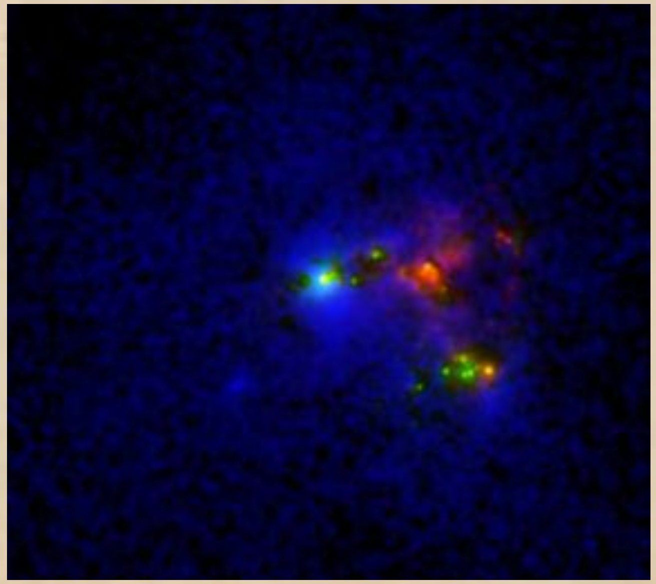

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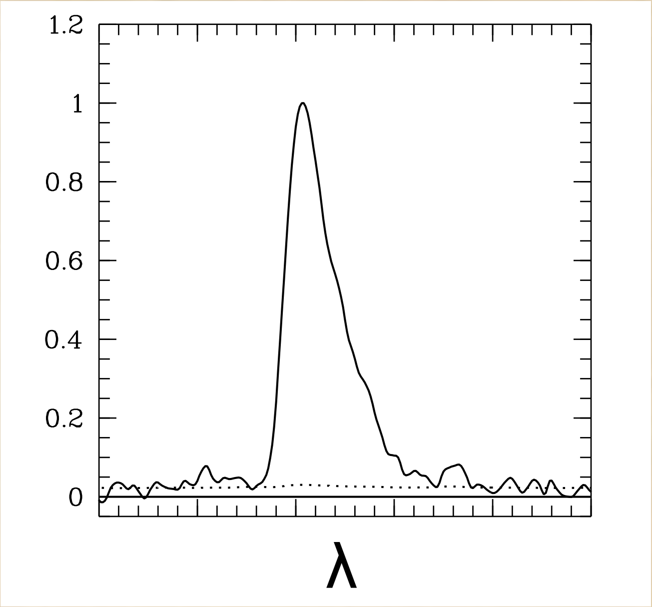

Tapken+07

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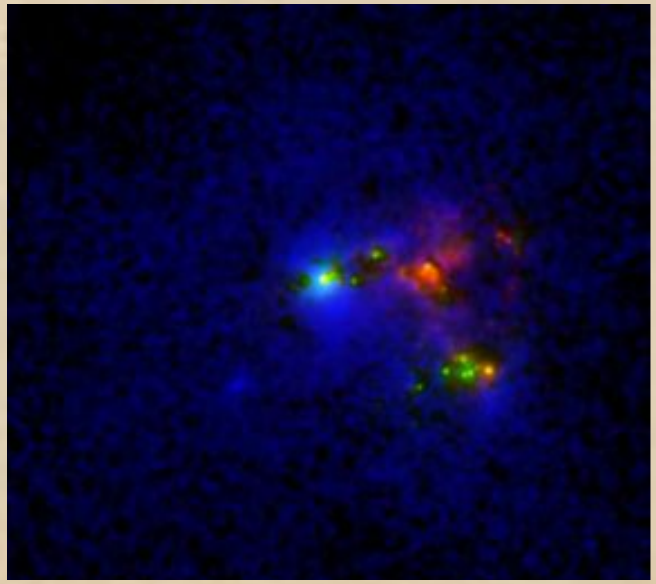

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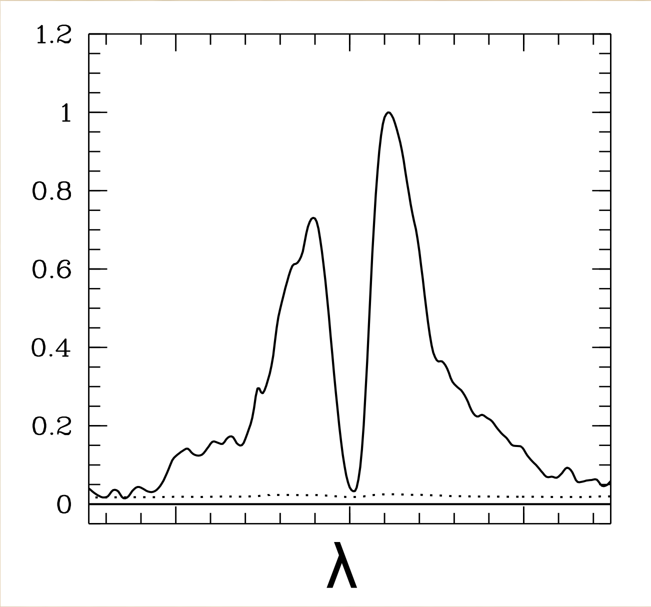


Tapken+07

Introduction - *Observational context*

Lyα Emitters (LAEs)

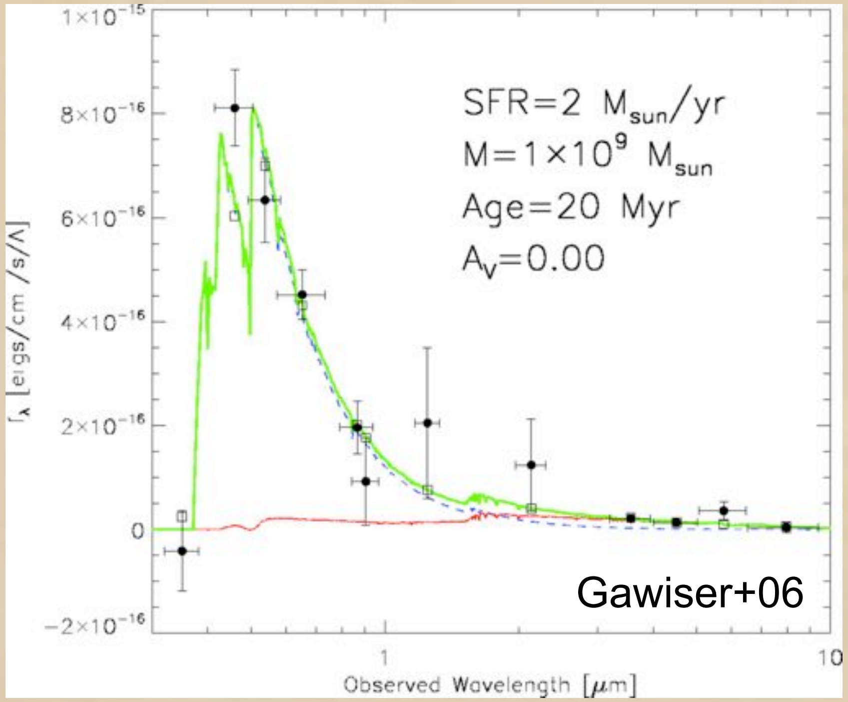
- photometric selection (narrow-band)
(e.g. Gronwall+07, Ouchi+08)
- blind spectroscopic surveys
(Blanc+11, Cassata+11)

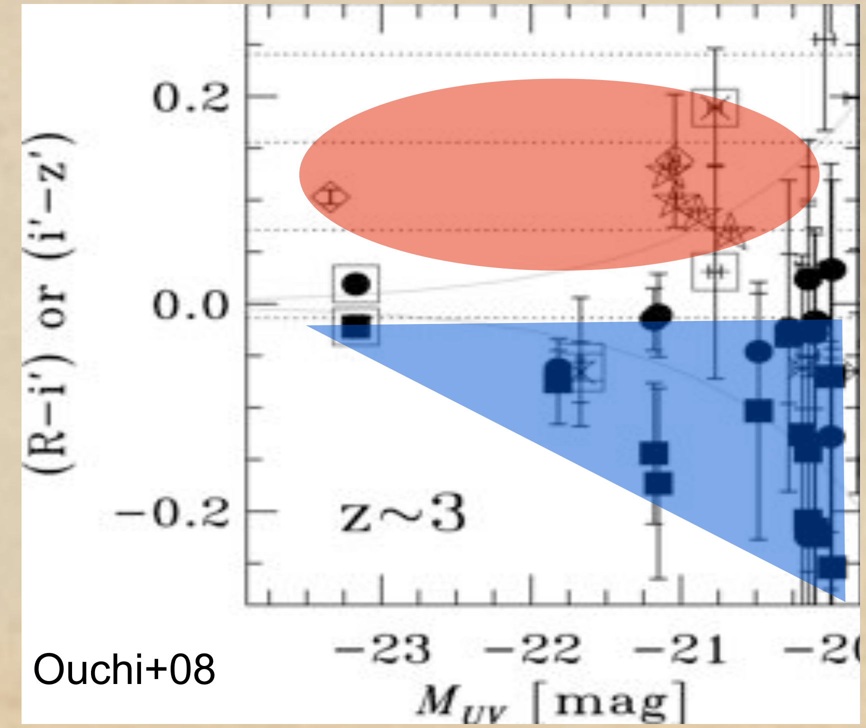
Lyman-break galaxies (LBGs)

- Broad-band selection (=> UV-bright)
(e.g. Steidel+99, Bouwens+07)
- ~ 50% of z=3 LBG show Lyα in emission
(Shapley+03)

LAEs on average **less massive, bluer, less dusty** and **younger than LBGs**

... but red, massive LAEs also found (Finkelstein+09)





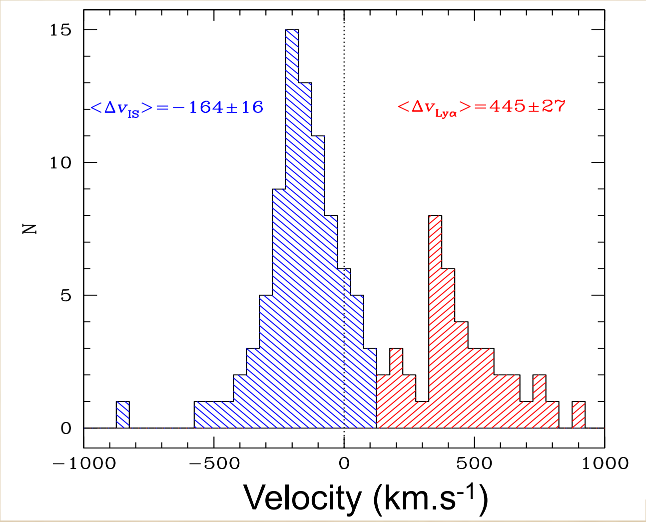
Introduction - *Observational context*

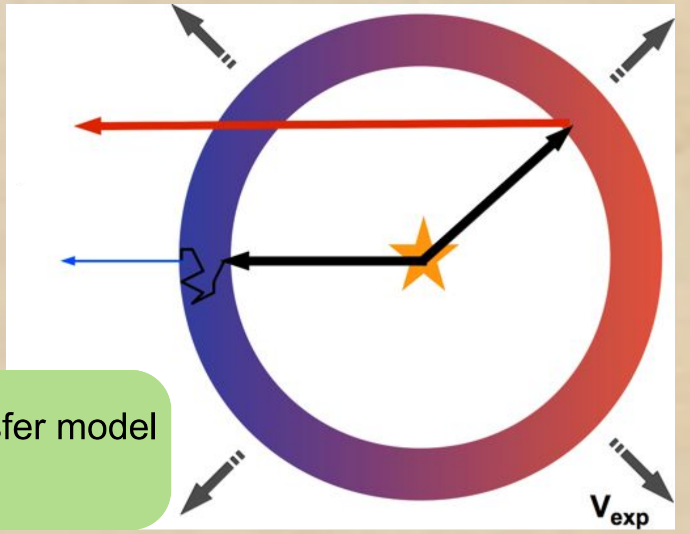
How do outflows affect Lyα profiles? (Kunth+98, Shapley+03, McLinden+10, Steidel+10)

Metal absorption blueshifted at $-V_{exp}$

Lyα emission redshifted at ~ $+2V_{exp}$

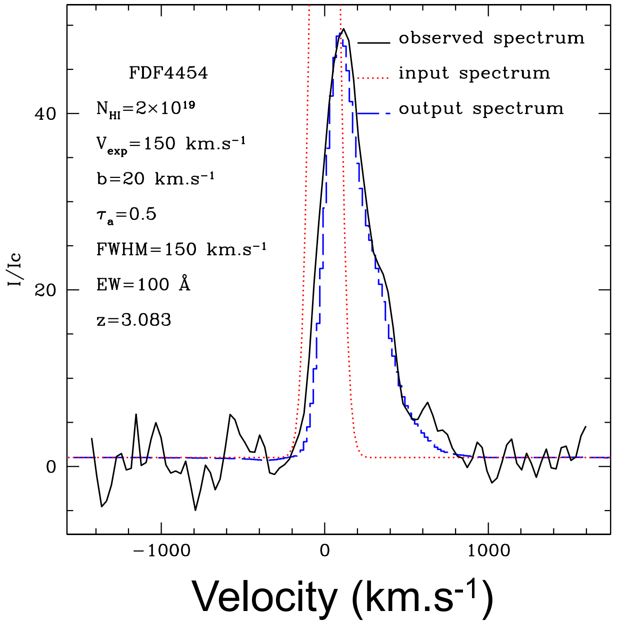
Steidel+10

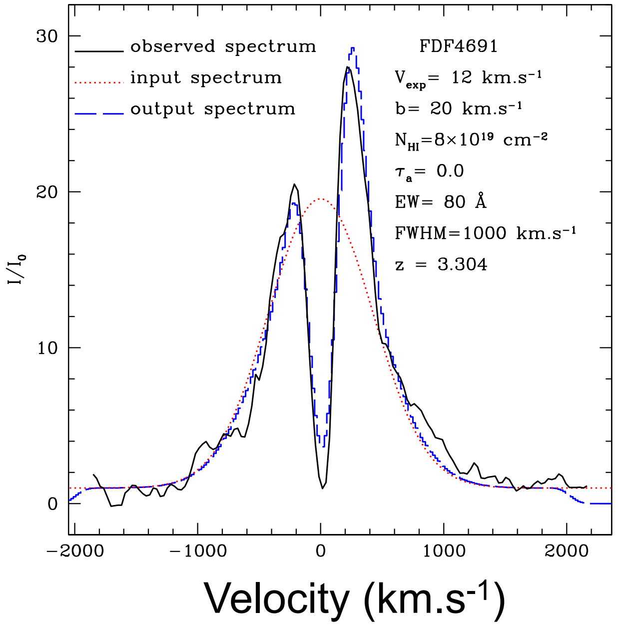


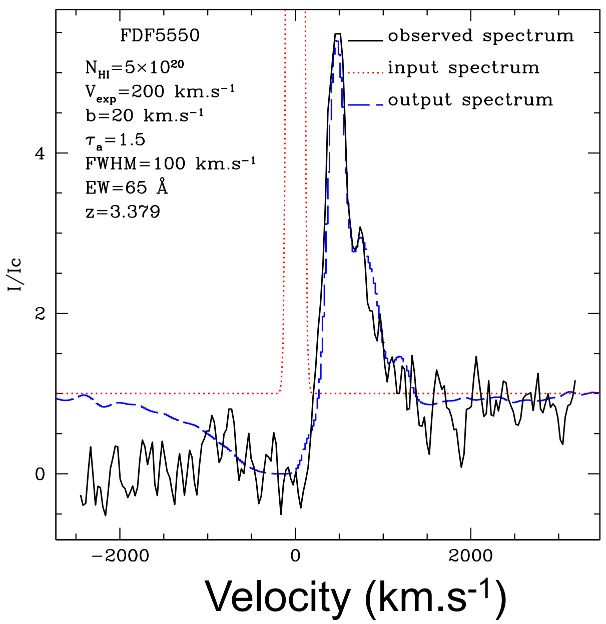


Monte-Carlo Lyα transfer model (Verhamme+06)

Fits of high-z Lyα profiles with shell model (Verhamme+08)







Introduction - *Motivations*

- *Nature of Lyα emitters (LAE) / overlap with LBGs*
- *Hierarchical evolution of LAEs (progenitors of local spirals?)*
- *Lyα as a probe of reionization ? (transition in terms of Lyα emission at z ~ 6-7 ?)*

<u>This talk:</u>

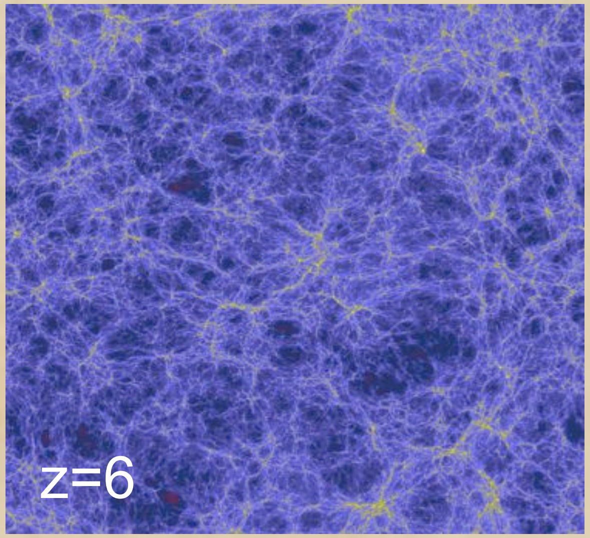
Test shell model in cosmological context (post-reionization epoch)

→ Coupling of SAM with Lyα transfer "shell model"

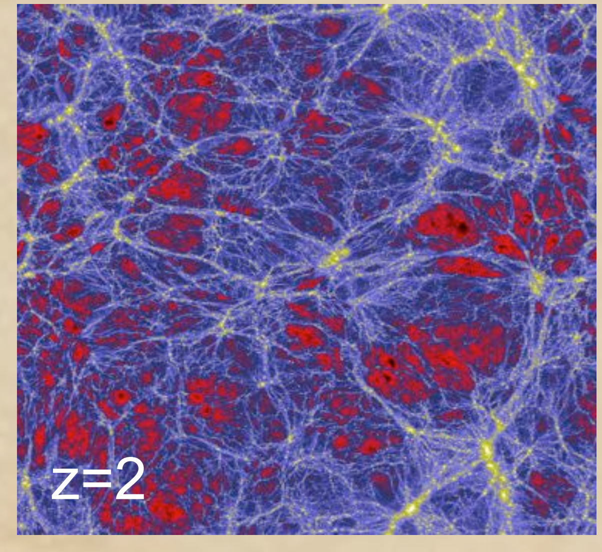
Garel+12, MNRAS ; Garel+13, in prep.

Semi-analytic model - *GALICS* (Hatton+03)

Cosmological simulation

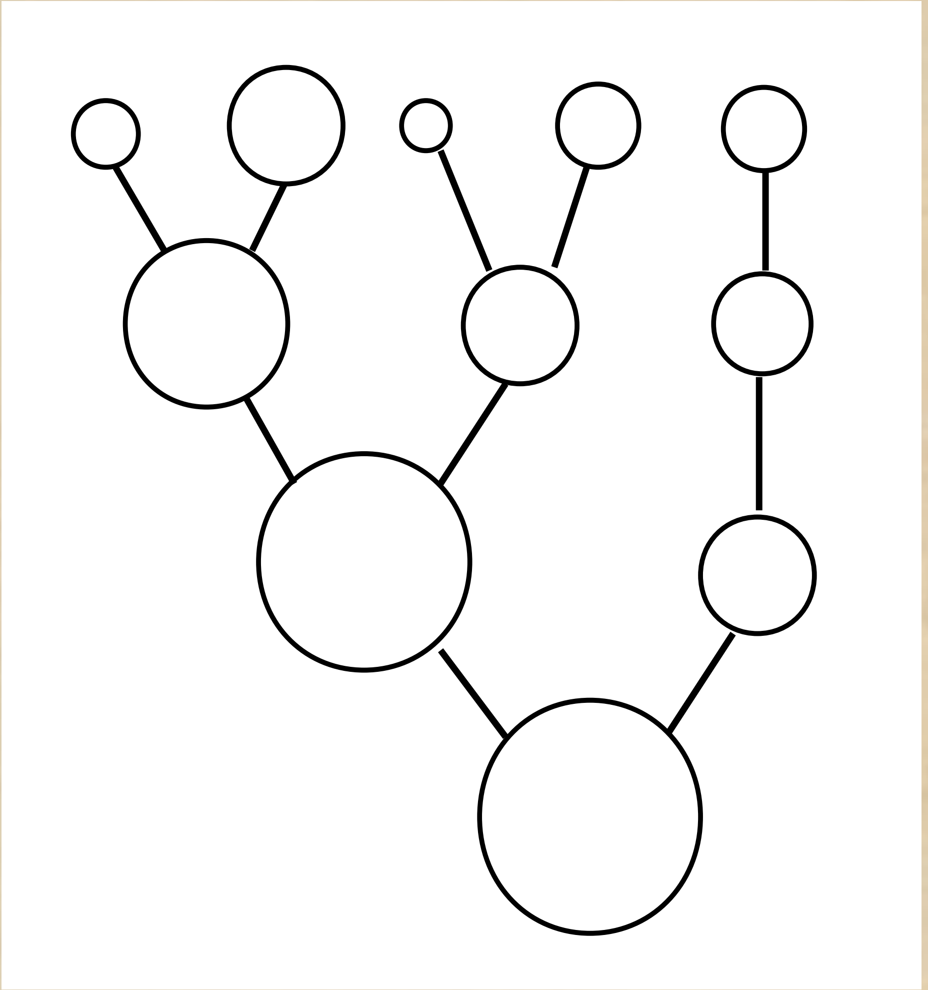


- L_{box} = 100 h^{-1} Mpc
- 1024^3 DM particles
- $M_{res} = 1.9 \times 10^9 M_\odot$
- WMAP-5 cosmology



Find DM halos (FOF)

Build merger trees
(Tweed+09)



Semi-analytic model - *GALICS*

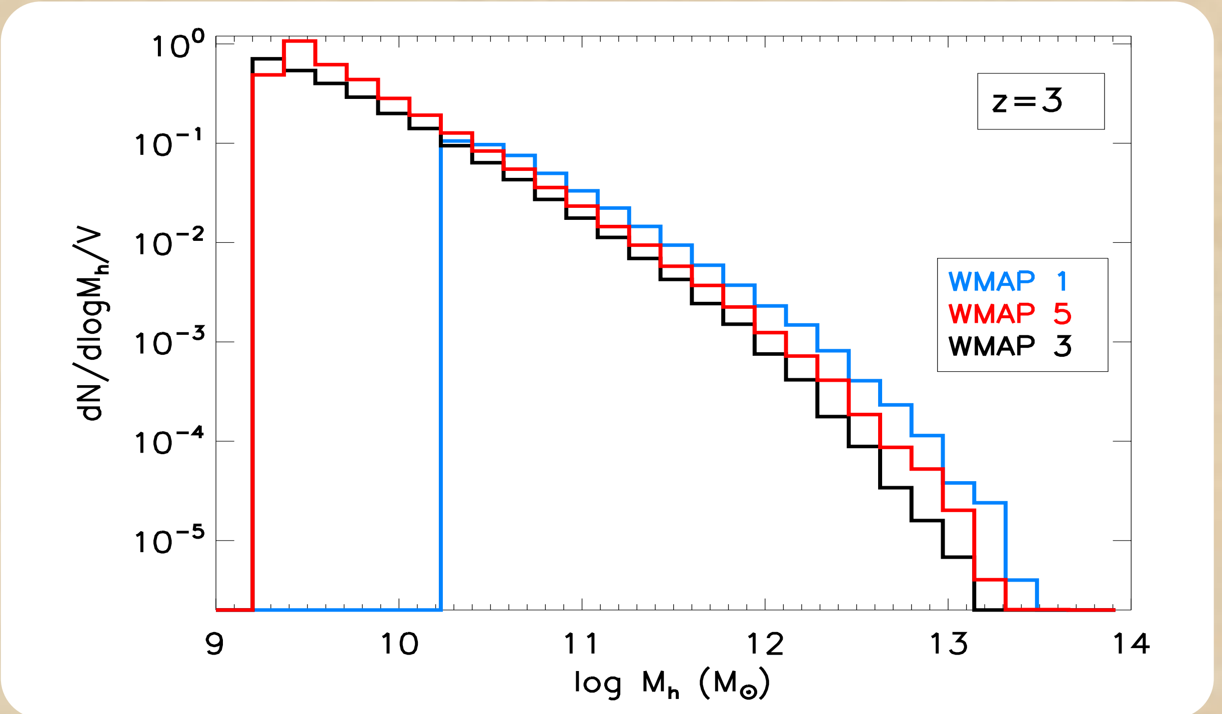
Cosmological simulation

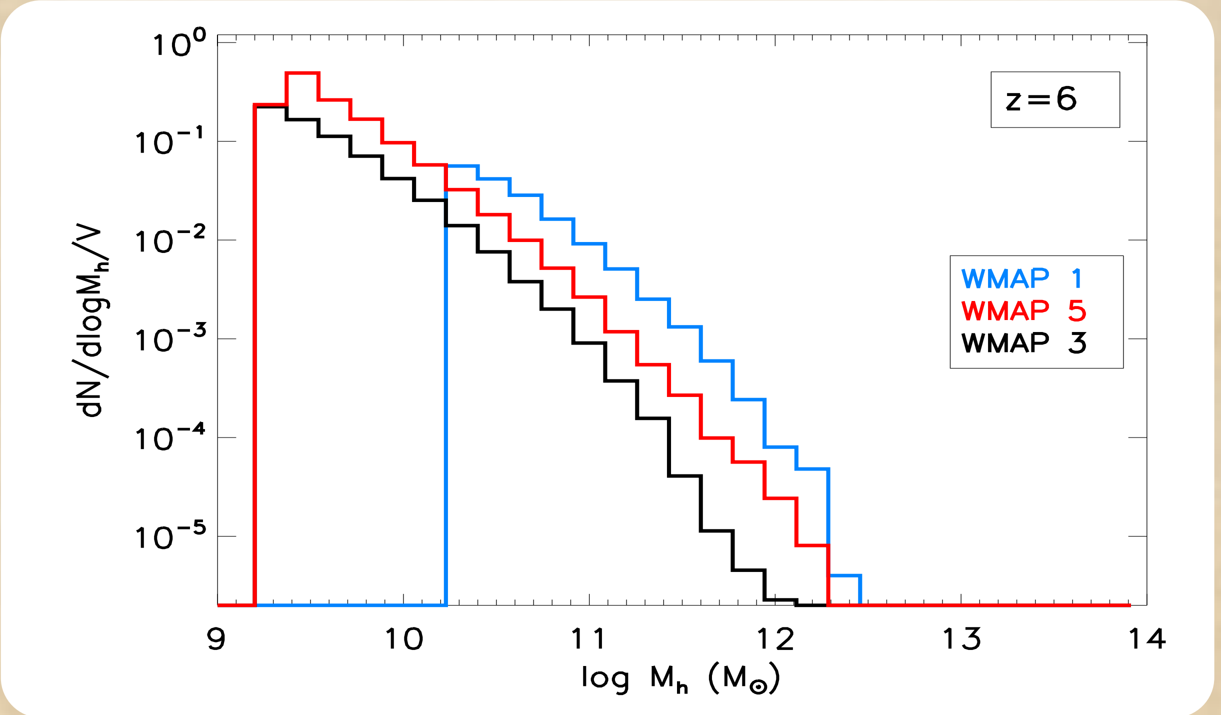
Original model (Garel+12):

- N-body simulation: WMAP-3 parameters
- cannot match UV/Lyα LF at z > 5

New model (Garel+13, in prep.):

- WMAP-5 cosmology
- Faster structure growth at high z





Semi-analytic model - *GALICS*

Time resolution

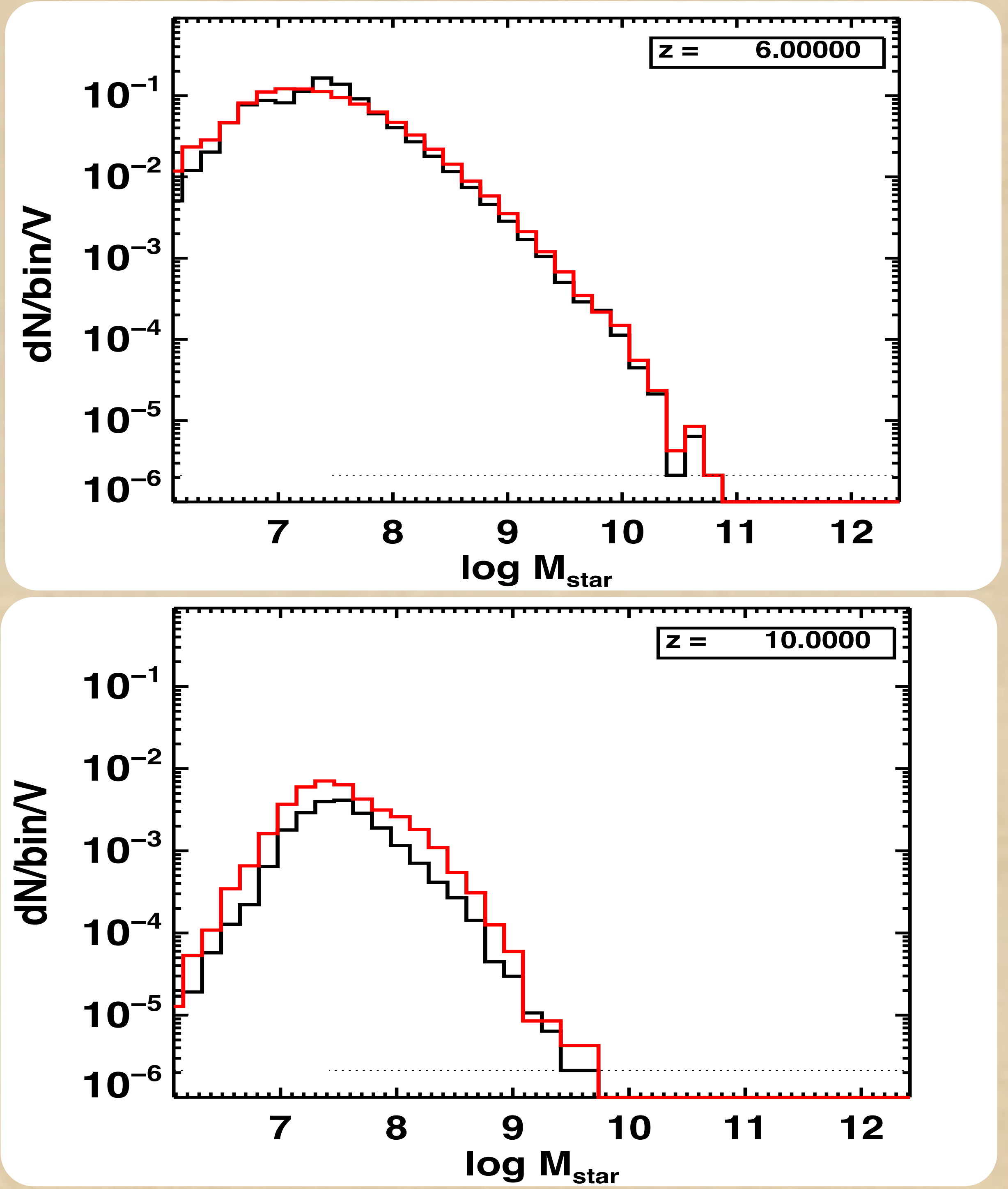
Simulation outputs regularly spaced

- **da = 0.01**

  Timestep > t_{dyn} at (very) high z

Simulation outputs irregularly spaced

- **dt(z) = t_{dyn}(z)**



Semi-analytic model - *GALICS*

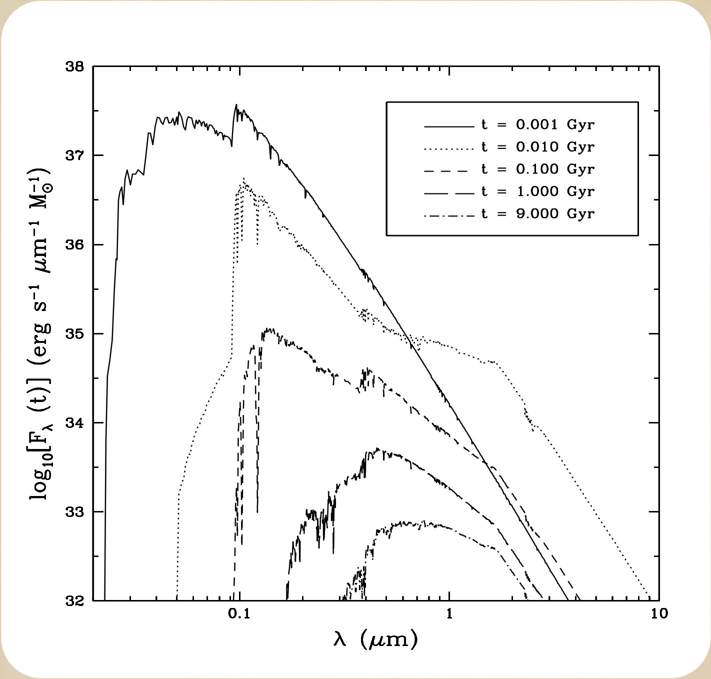
Modelling of galaxies

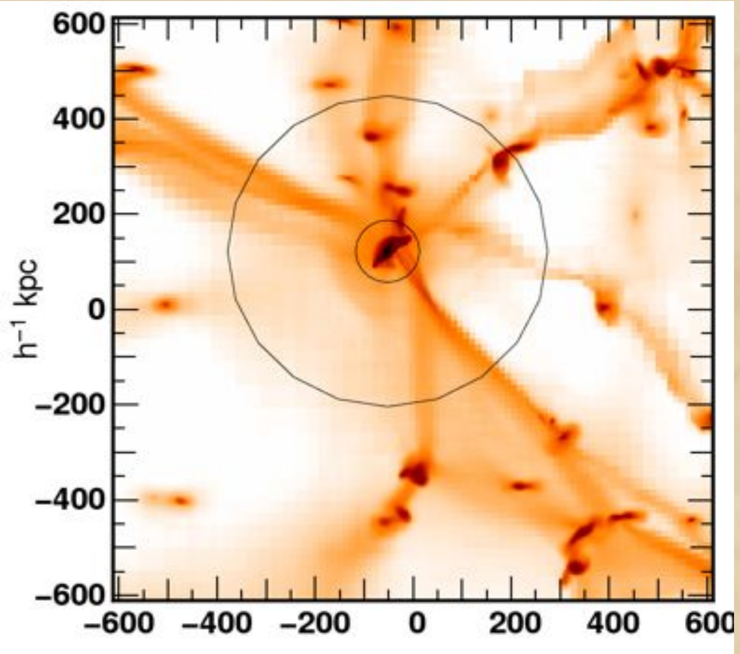
Original SAM (Hatton+03)

- standard prescriptions for galaxy evolution
- coupling with stellar synthesis models (Stardust, Devriendt+99)

Updates (Garel+12)

- Cold accretion (streams) replaces cooling
- Migration of clumps to “starburst region”
- Kennicutt law (efficiency x 5)
- strong SN feedback





Ocvirk+08

Semi-analytic model - *Lyα transfer*

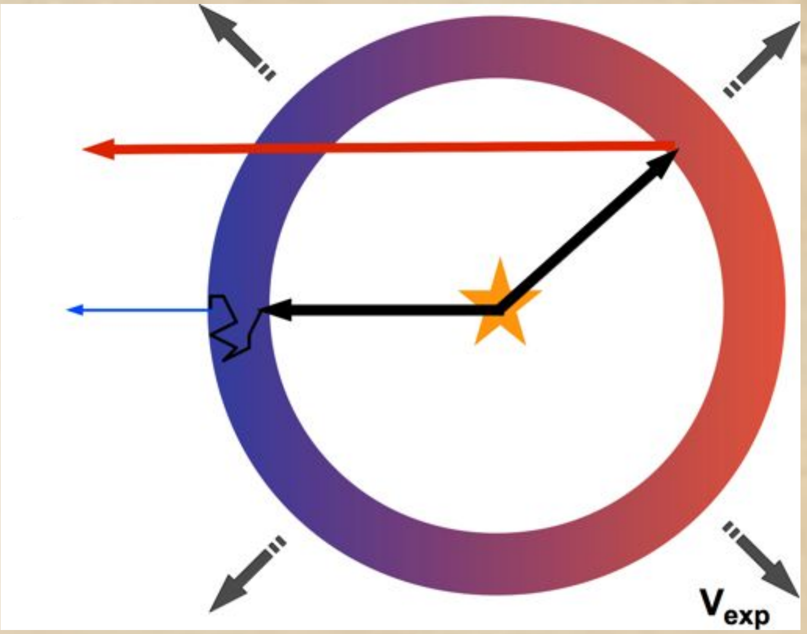
- Shell parameters

✗ expansion velocity $\mathbf{V_{exp} \sim SFR^{1/6}}$
(Bertone+05)

✗ HI column density $\mathbf{N_{HI} = f_{shell}\, M_{HI} / (4\pi R^2)}$

✗ dust opacity $\boldsymbol{\tau_{dust} \sim (Z / Z_\odot)^{1.6}\, N_{HI}\, (1+z)^{1/2}}$
(Guiderdoni+87) dust-to-gas ratio evolution (Reddy+06)

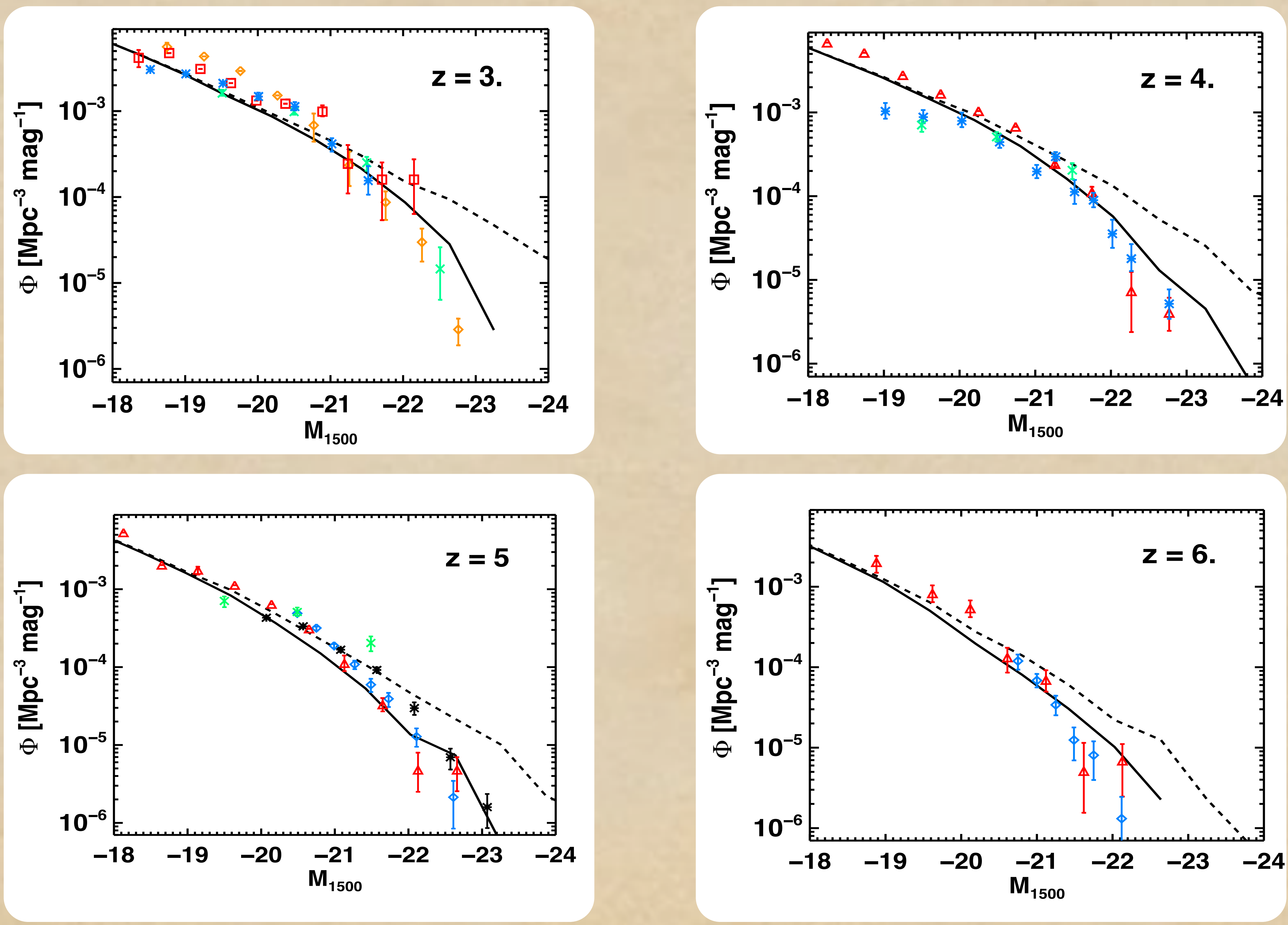
✗ velocity dispersion $\mathbf{b = 20\ km.s^{-1}\ (T = 10^4\ K)}$



- Library of ~ 6000 Lyα transfer models in shells (Schaerer+11)

→ **Lyα profile** and Lyα photons **escape fraction f_{esc}**

UV luminosity functions

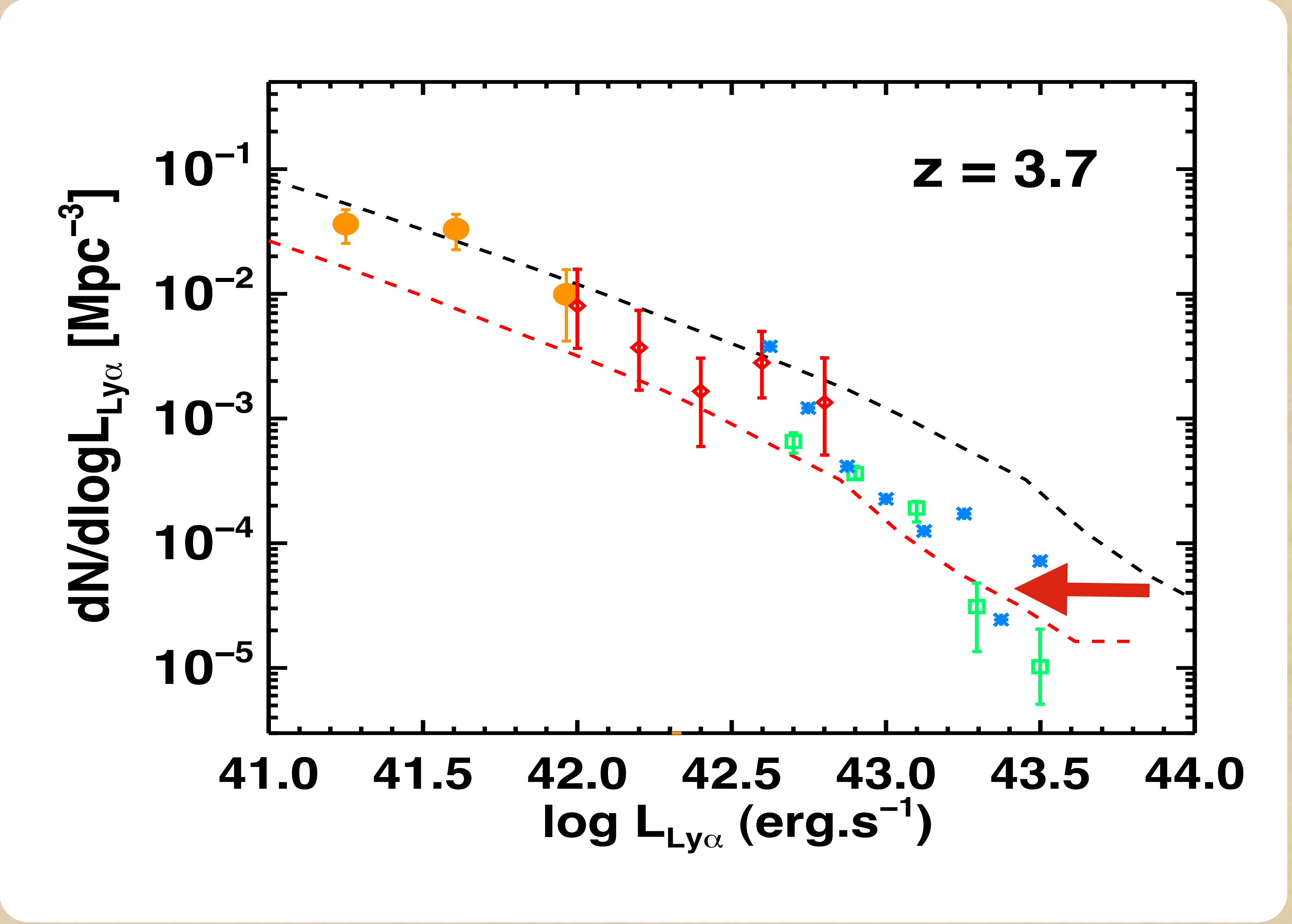


Lyα luminosity functions

Intrinsic

constant f_{esc}

LeDelliou+06, Nagamine+10



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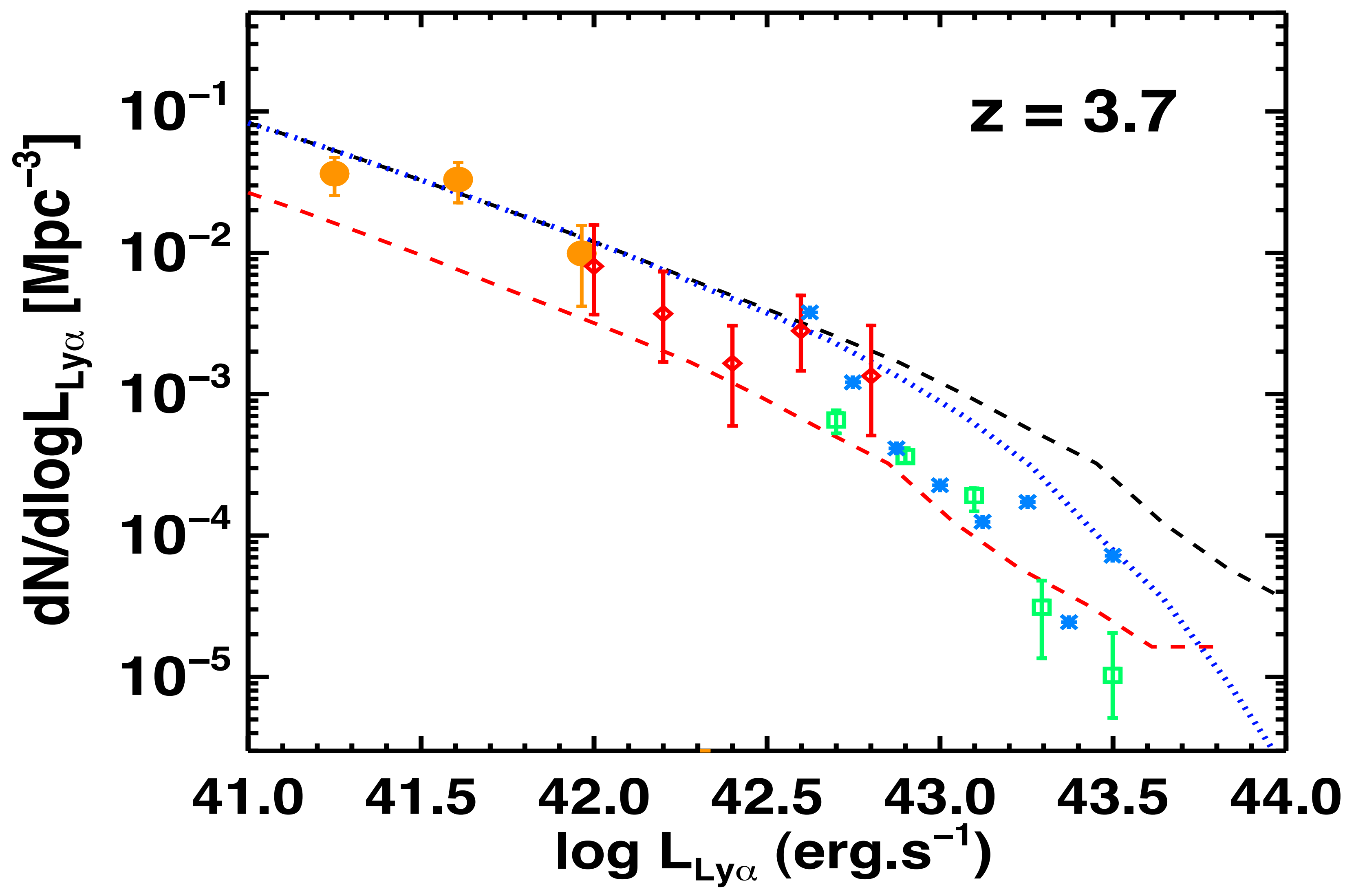
$f_{esc} = \exp(-\tau_{dust})$

Mao+07, Kobayashi+07



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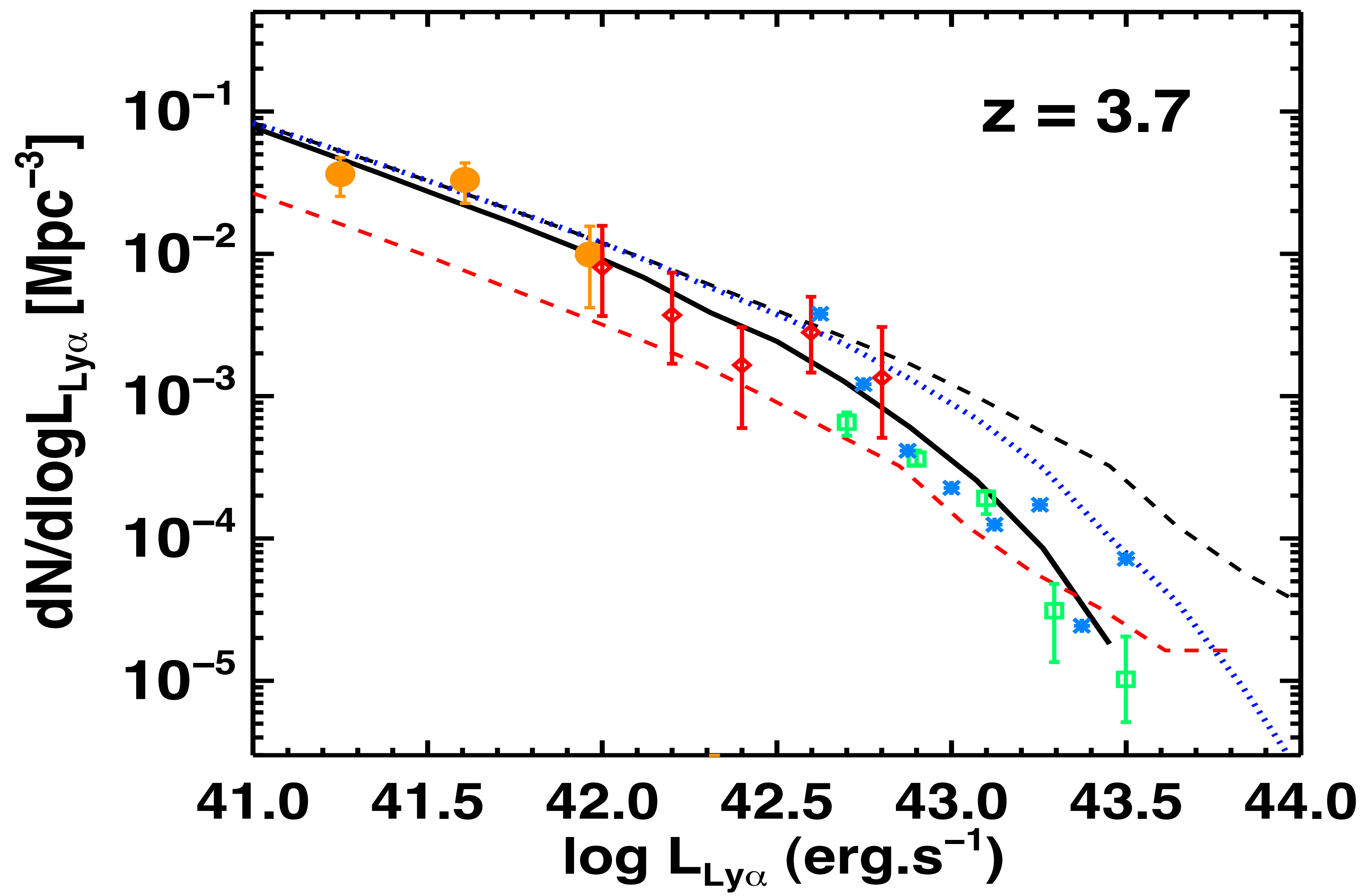
Shell/resonant scattering



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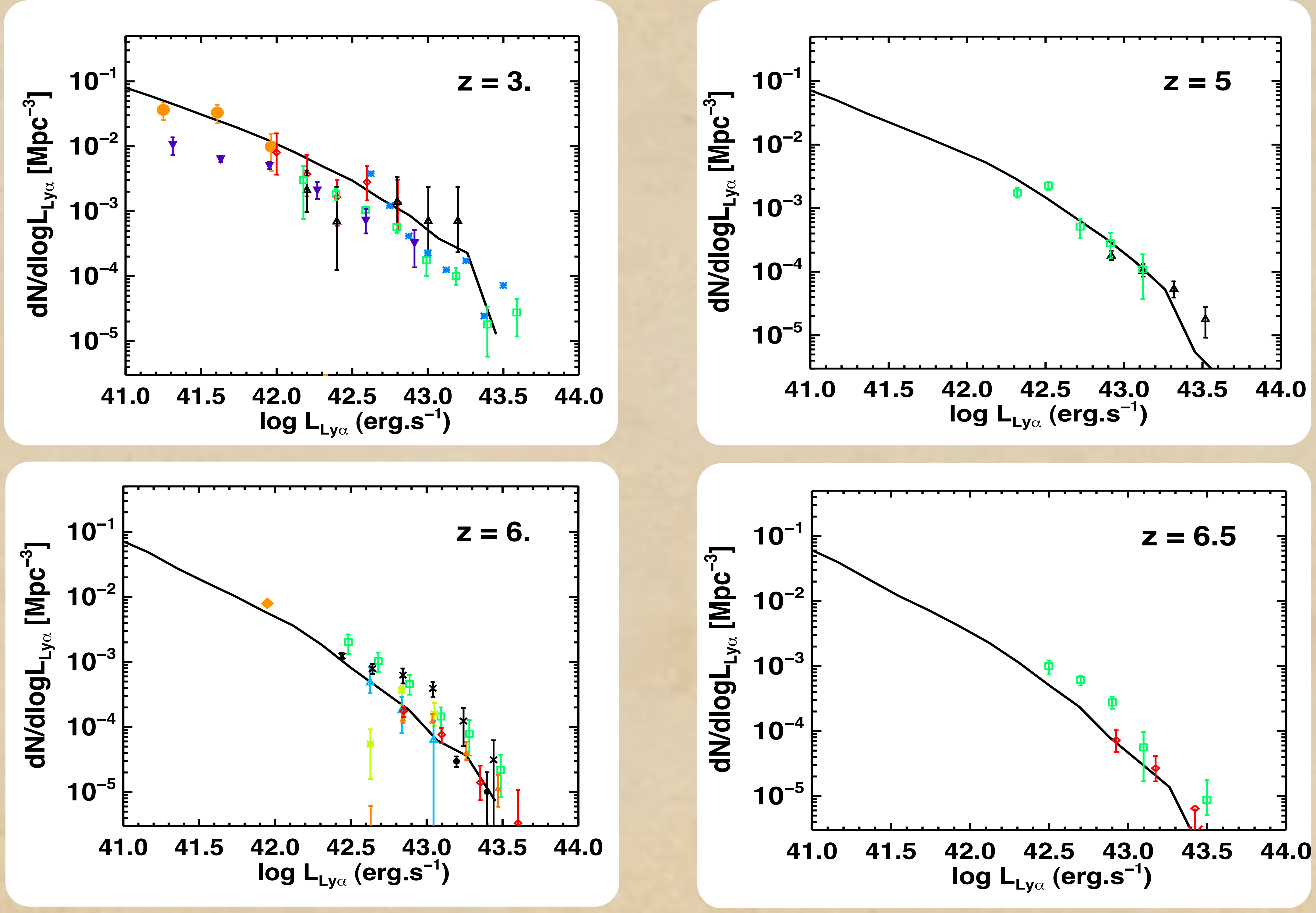


Lyα escape fraction

f_{esc} distribution vs SFR

- low-SFR (M_{star}) galaxies

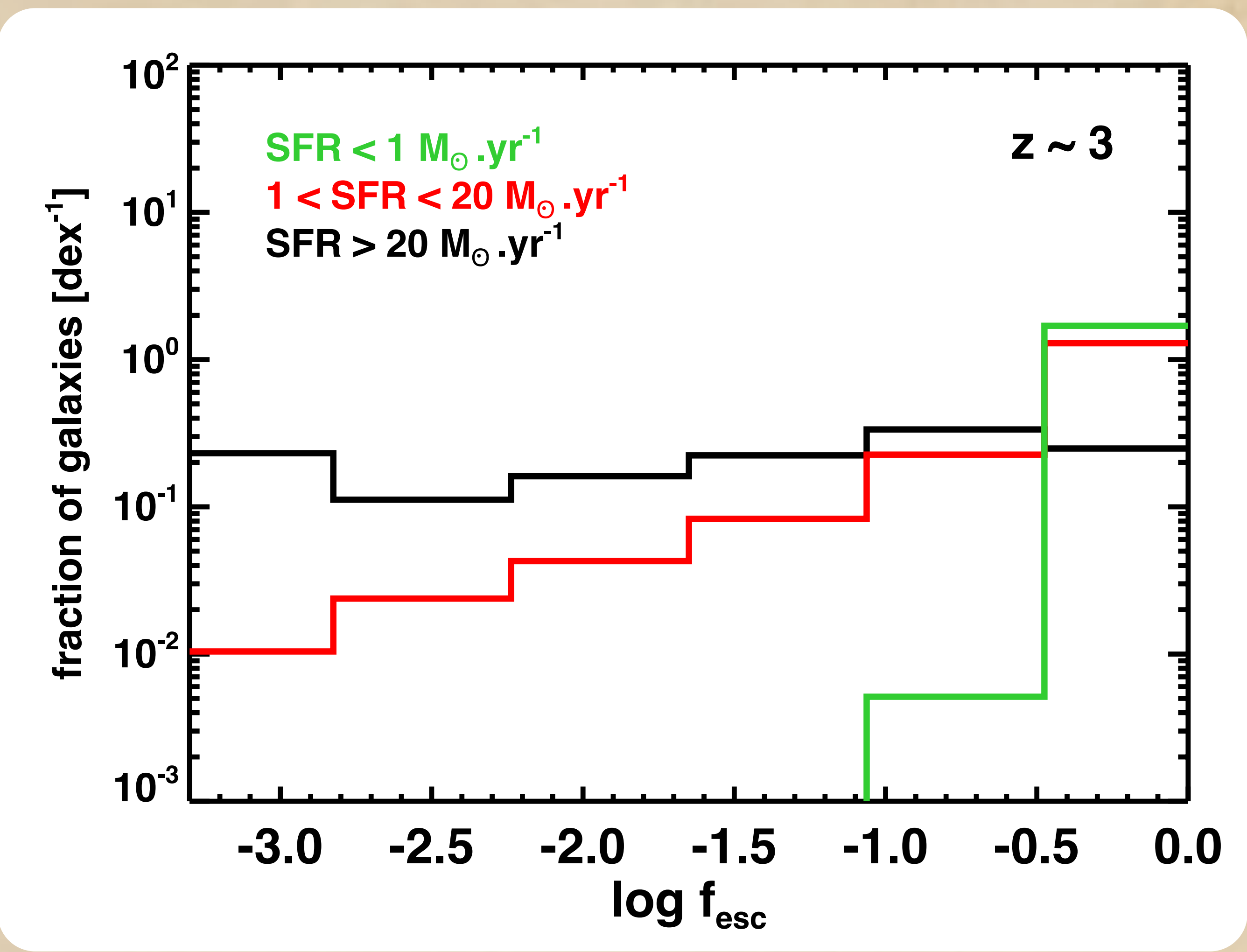
  $f_{esc} \sim 1$

  $SFR \sim L_{Ly\alpha} / (10^{42}\ erg.s^{-1})$

- high-SFR (M_{star}) galaxies

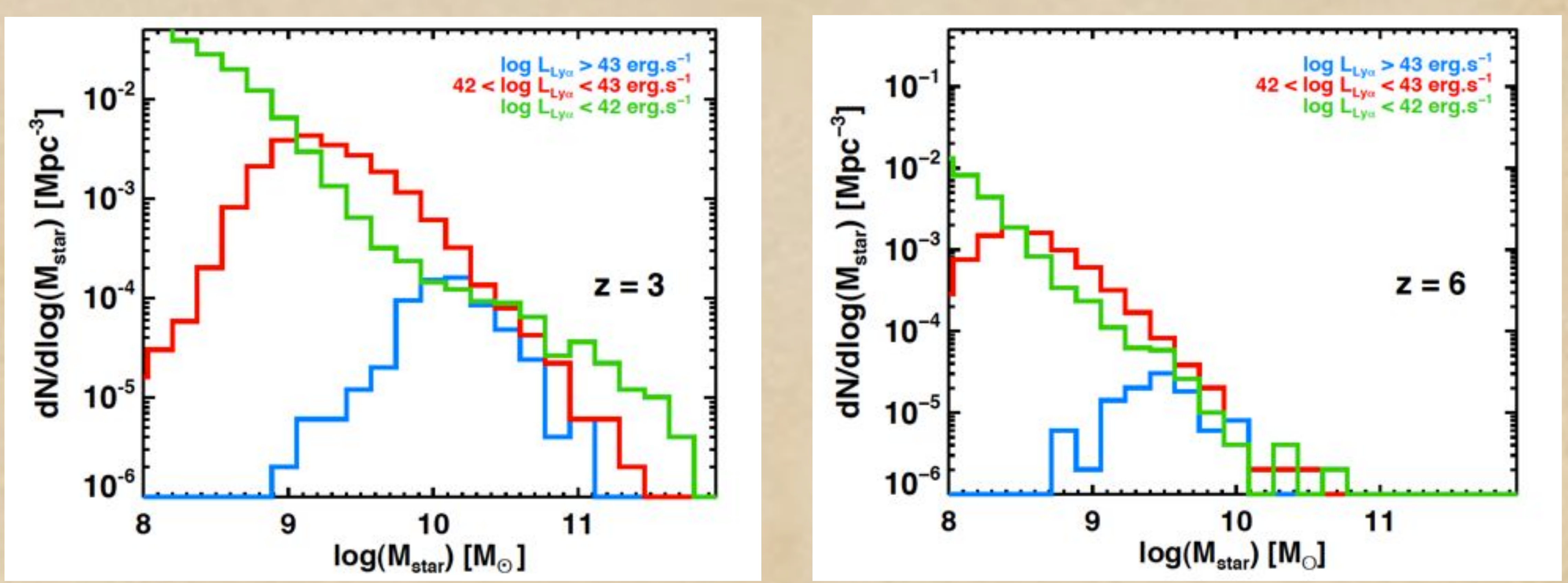
  ~ uniform (log) f_{esc} distribution

  Lyα can't be used to trace SFR



Stellar Masses

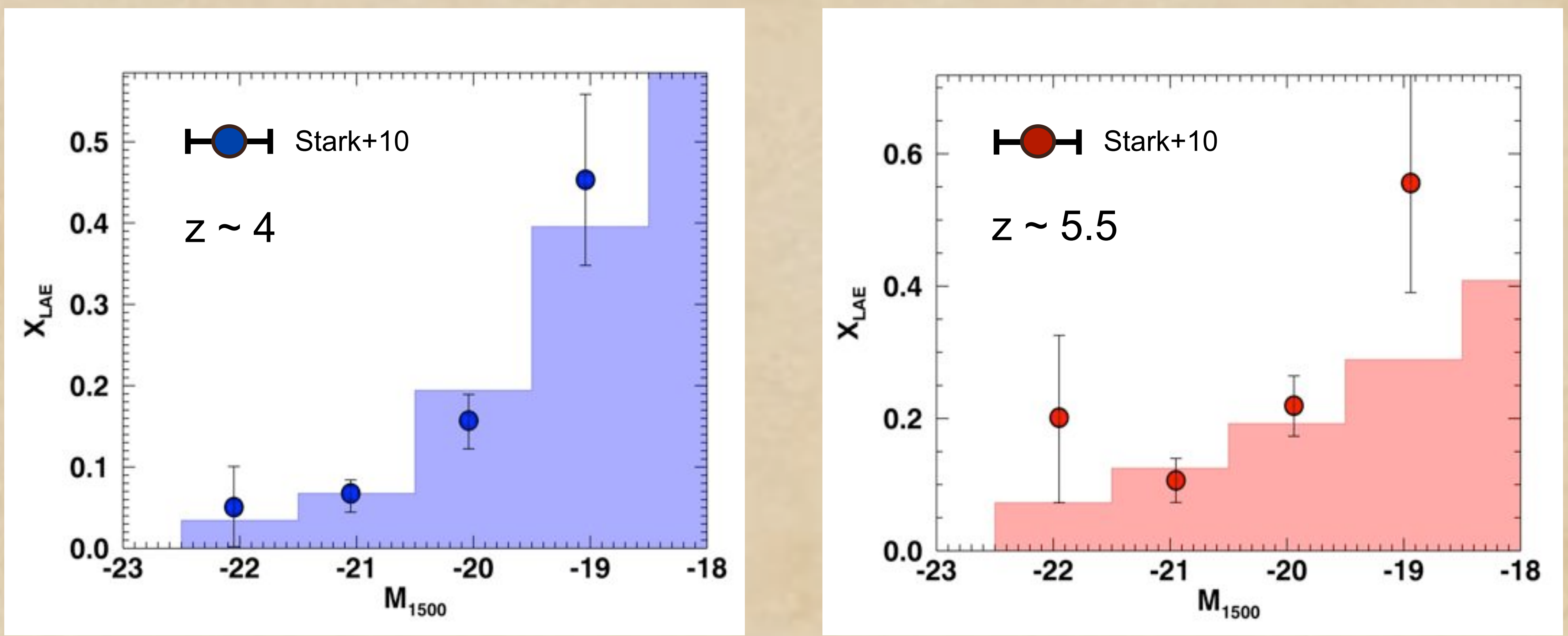
***M_{star} per $L_{Ly\alpha}$* bin**



- "Typical" LAEs have median $M_{star} \sim 10^9\ M_\odot$ but cover wide mass range
- Brightest LAEs are not most massive galaxies
- Massive objects (~ LBGs) can have various Lyα intensities

Fraction of line emitters in LBG samples

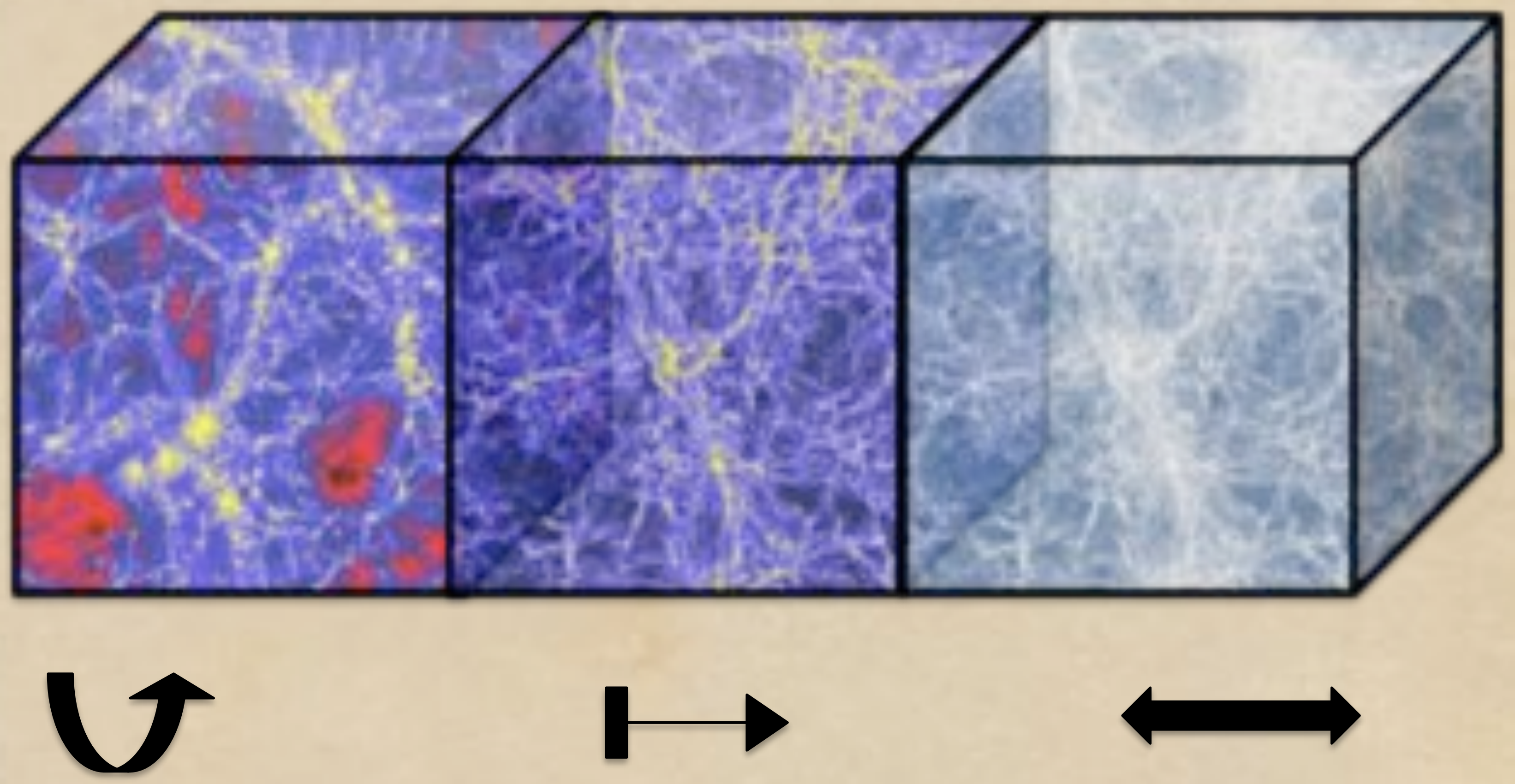
X_{LAE} vs M_{1500} in (faint) LBGs with Keck spectroscopy ($EW_{Ly\alpha}$ >≈ 50 A)



Lyα properties **per bin of UV mag** (~SFR) quite well reproduced

Lightcones

- Draw lightcones through the boxes (MOMAF, Blaizot+06)



Apply transformation to the box to avoid replication effects

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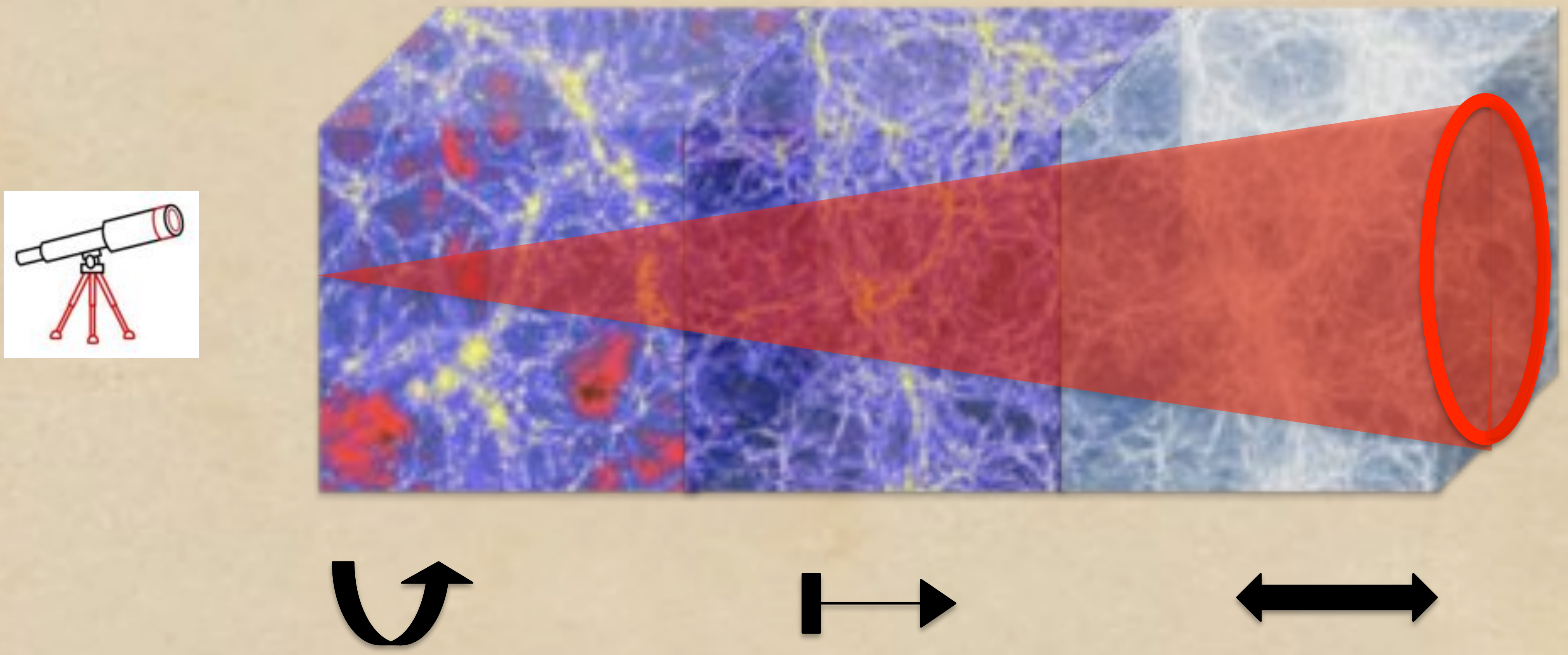
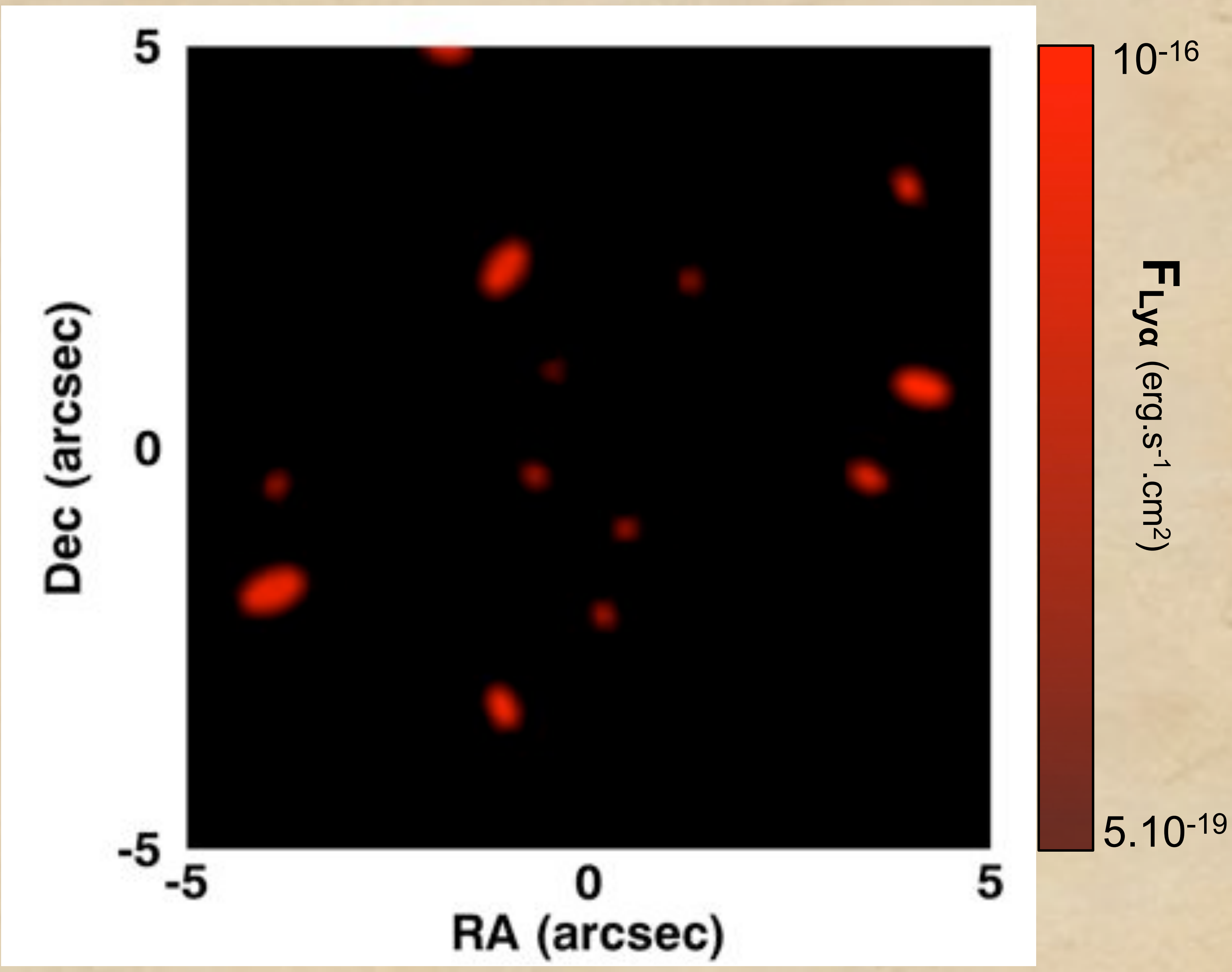


Apply transformation to the box to avoid replication effects

Mock fields - *Examples*

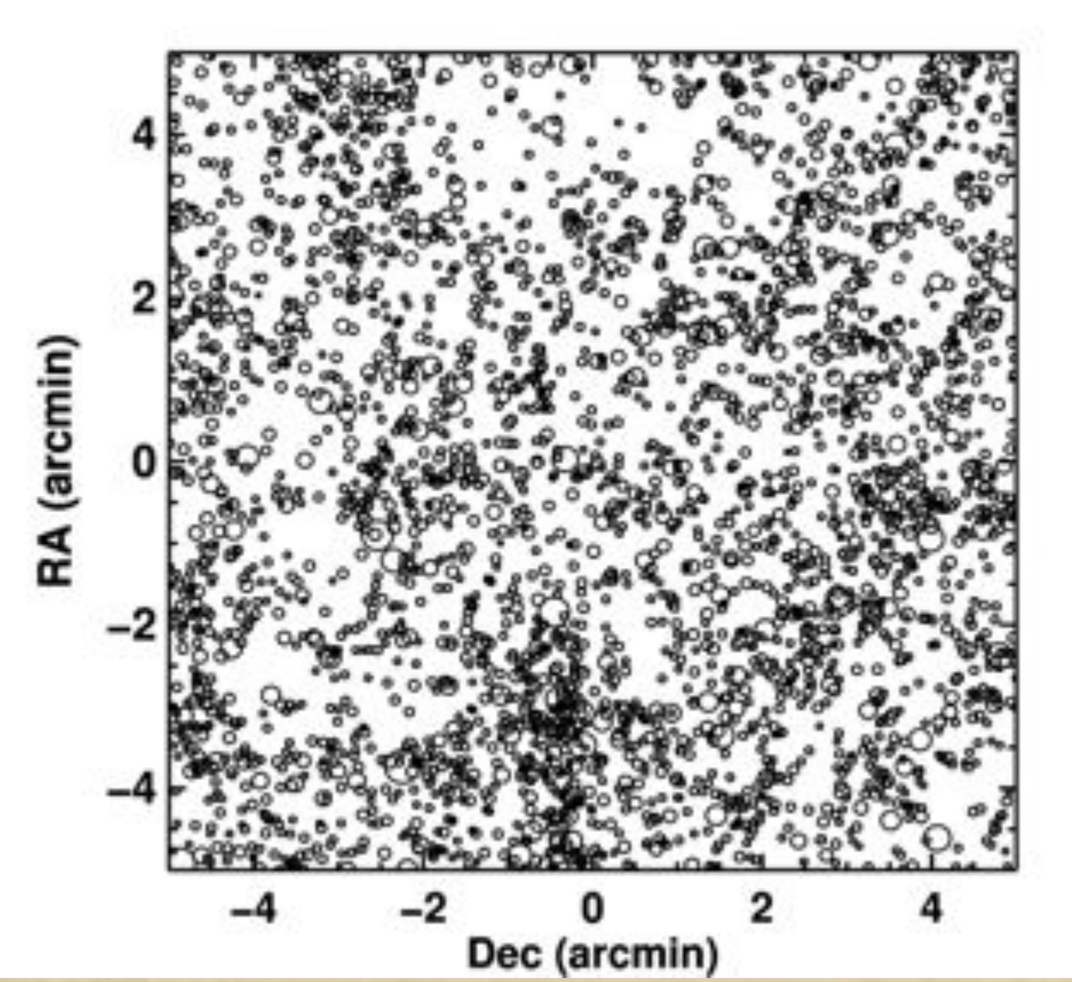
- Mock field of LAEs
- FoV : 100 arcsec^2
- $F_{Ly\alpha} > 5.10^{-19}$ erg.s^{-1}.cm^{-2}
- $3 < z < 6$



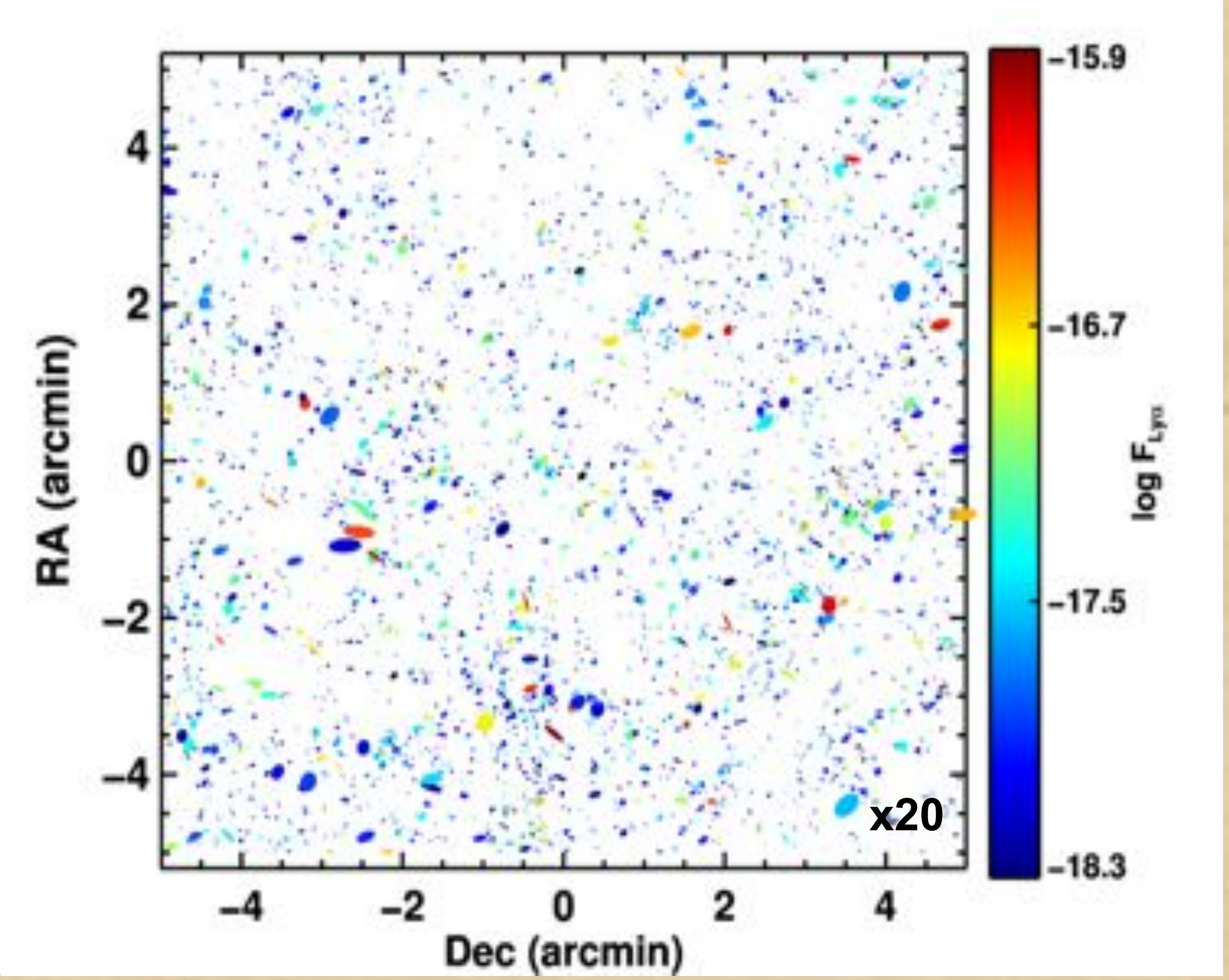
Mock fields - *Examples*

- field of 100 arcmin^2
- $F_{Ly\alpha} > 5.10^{-19}$ erg.s^{-1}.cm^{-2}
- $3 < z < 3.1$

DM halos



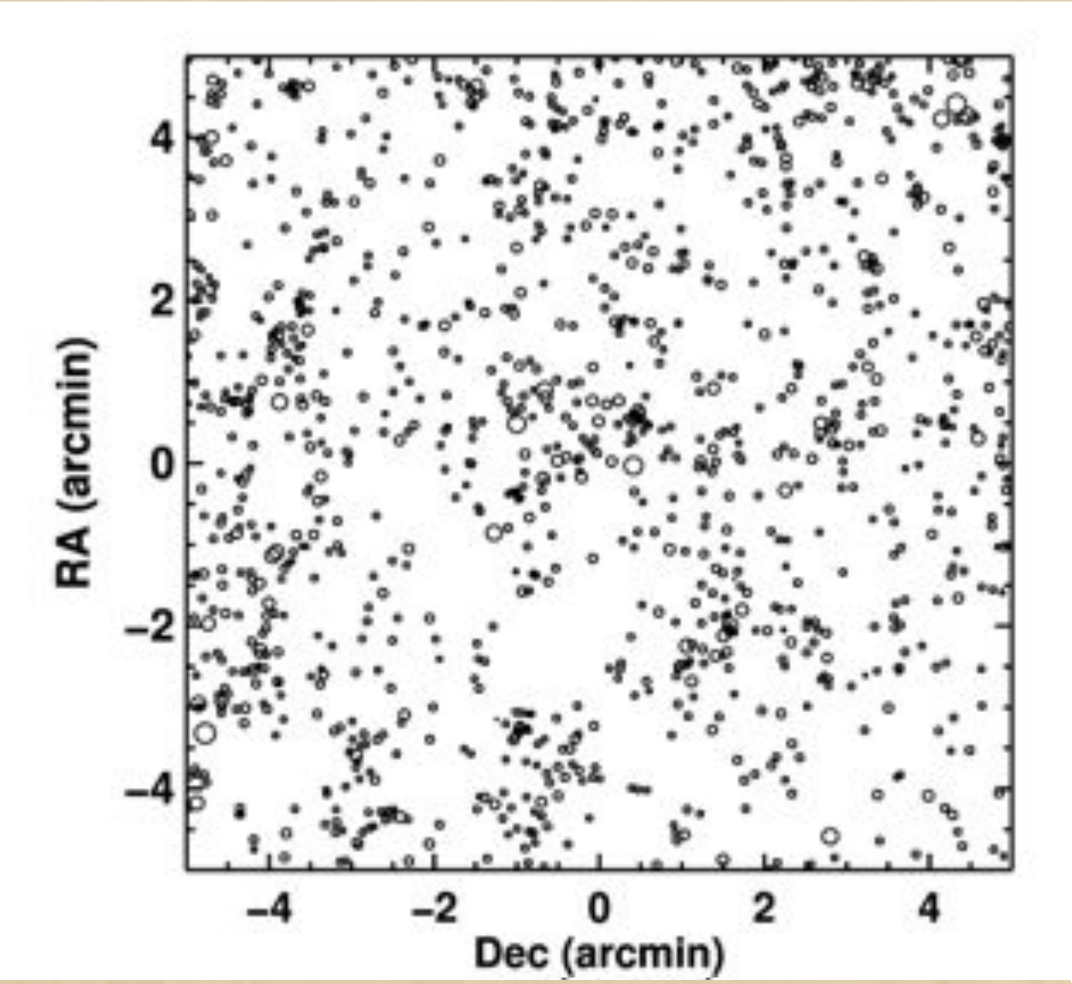
LAEs



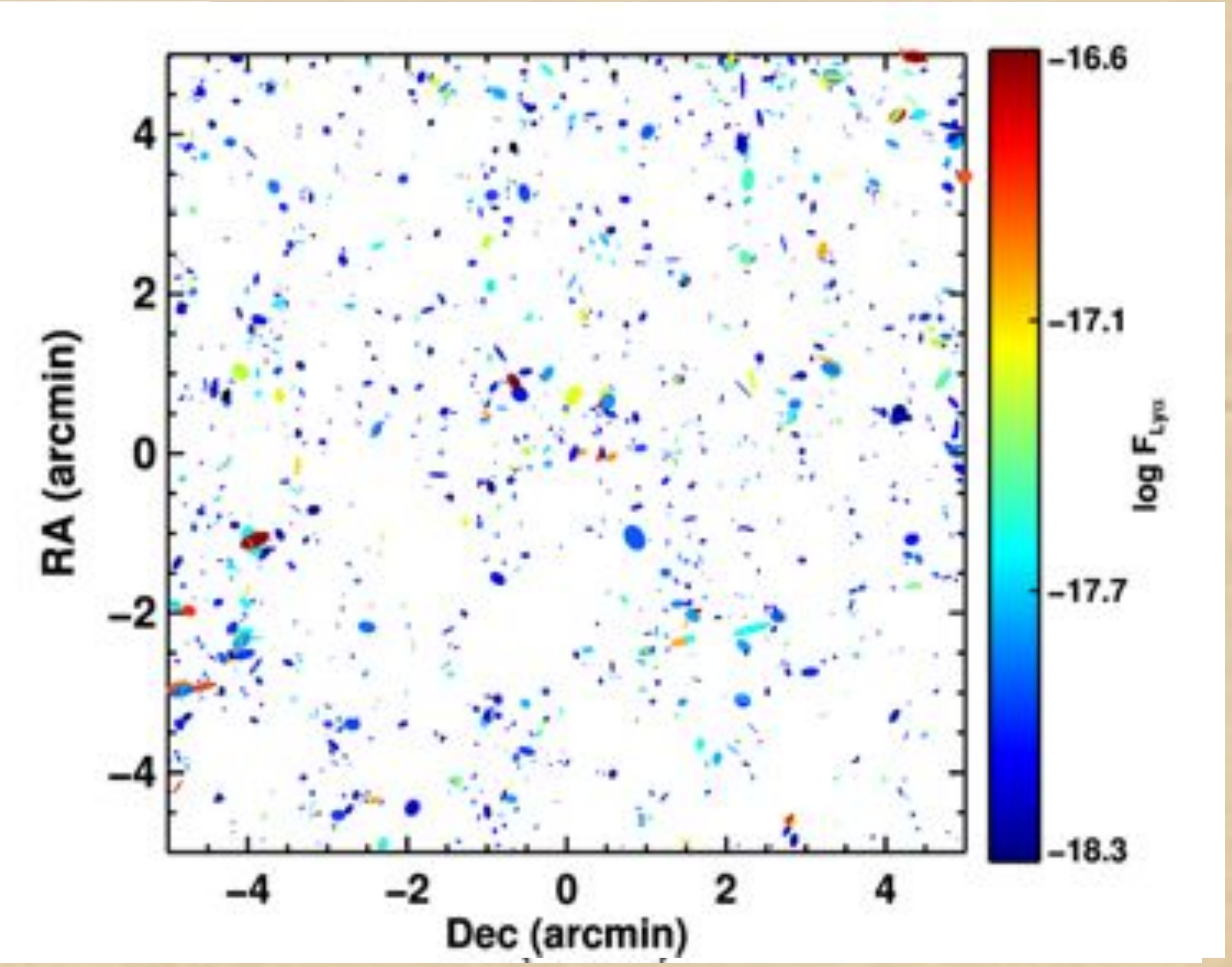
Mock fields - *Examples*

- field of 100 $arcmin^2$
- $F_{Ly\alpha} > 5.10^{-19}$ $erg.s^{-1}.cm^{-2}$
- $5.5 < z < 6$

DM halos



LAEs



Clustering - *Angular correlation function w(θ)*

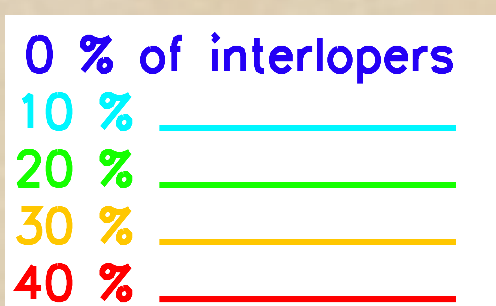
Are LAEs in the right halos?

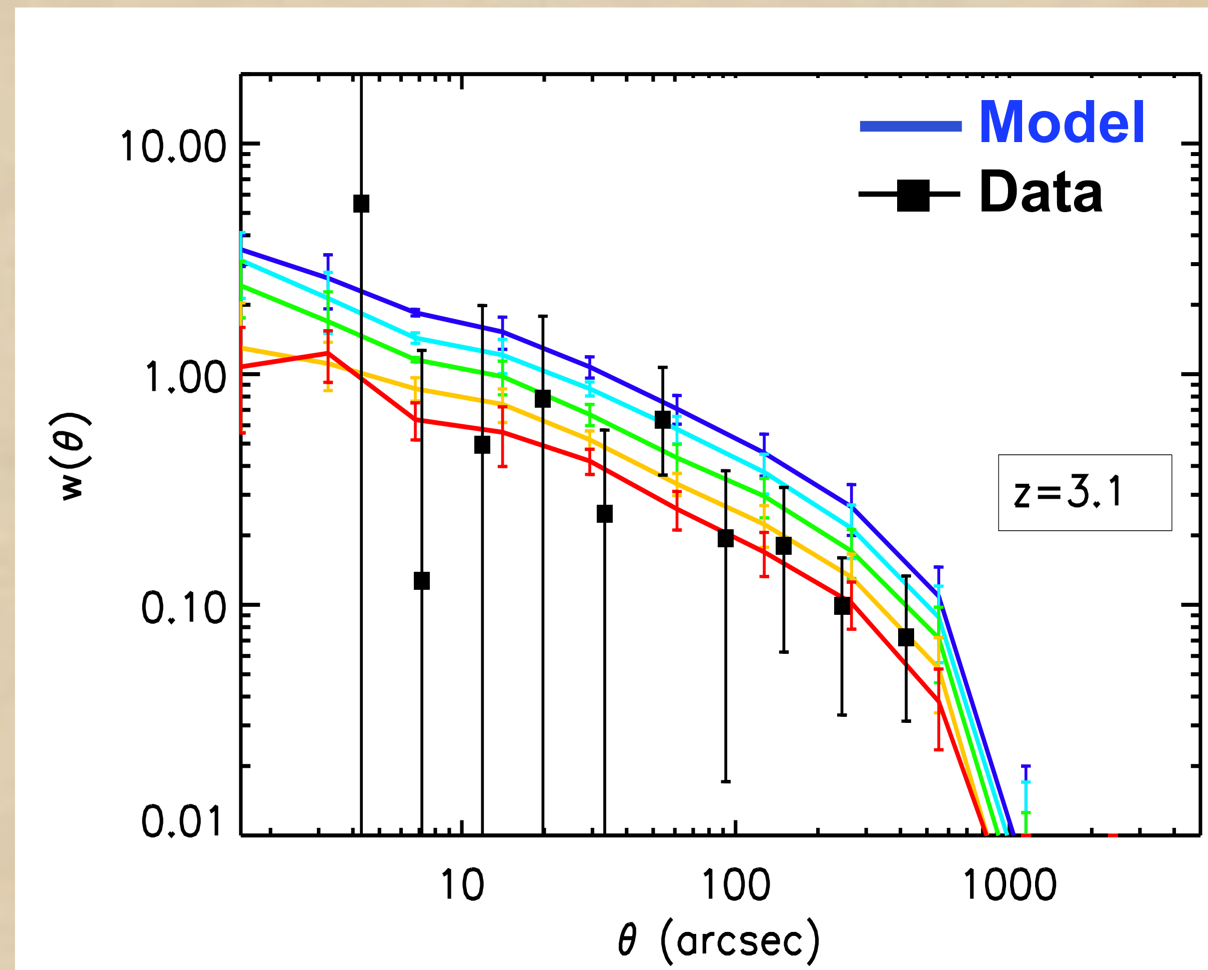
- ACF measured in Wide-field narrow-band surveys

- Samples contaminated by low-z interlopers

- Contamination rate ~ 20-30%
  (Ouchi+08, Hu+10)

→ Add random sources in mocks to mimic interlopers:





Conclusions

- Simple model for Lyα emission/transfer able to reproduce many obs. data (e.g. LAE / LBG connection)

- But : - inhomogenous data (esp. LFs) makes things easier
  - some mismatchs (e.g. $EW_{Ly\alpha}$ distribution)

- Look at hierarchical evolution of high-z LAEs (MW halos at z=0?)

- Do we need to invoke x_{HI} evolution to explain z > 6.5 Lyα data ?