The Clustering of Lyα emitters in a ΛCDM Universe

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Clustering of high redshift Lyα emitters

What can we learn from it?

- Spatial distribution of Lyα emitters
  - Are they distributed like other galaxies?
  - Where are they more likely to be found?
  - How are Lyα emitters tracing the underlying dark matter distribution?
- The mass of dark matter haloes hosting Lyα emitters
- Galaxy formation in the high redshift Universe
  - What ingredients do we need to reproduce the observed large scale structure of Lyα emitters?
  - How reliable are current measurements really? (cosmic variance)

Our model

We use the **GALFORM** semi analytical model described yesterday in Cedric's talk

- Baugh et al (2005); Le Delliou et al (2005,2006); Lacey et al (2008)
- Kennicut IMF for quiescent galaxies
- Top-heavy IMF for starbursts (boost 5x the number of ionizing photons)
- Superwinds suppress the formation of bright galaxies
- LyC photons + Case B recombination $\Rightarrow$ Lyα photons
- A fixed escape fraction $f_{\rm esc} = 0.02$ is assumed
  $\Rightarrow$ to fit observed LF at $z \sim 3-6$

Beyond Lyα emitters

- Observed number counts and redshift distribution of sub-millimetre sources
- Luminosity function of Lyman-break galaxies
- Galaxy evolution in the IR

Our model

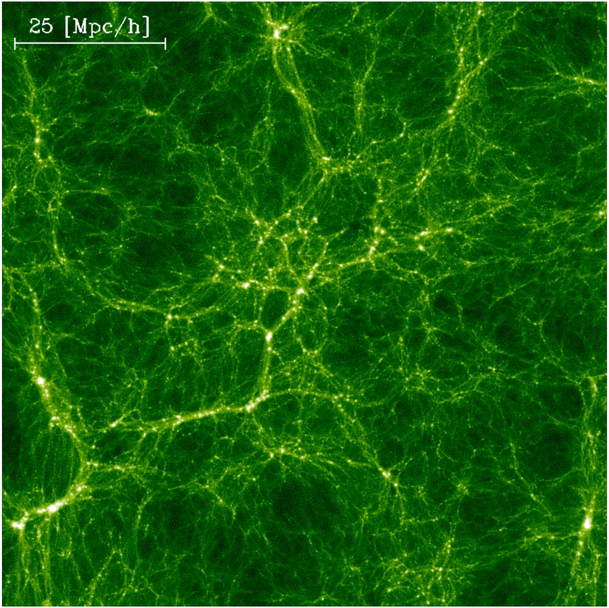
- We combine it with the Millennium Simulation (Springel et al.(2005))
  - Box size: 500[Mpc/h] each side.
  - $M_{halo} \geq 1.72 \times 10^{10} M_{\odot} h^{-1}$

$\Longrightarrow$ Spatial information

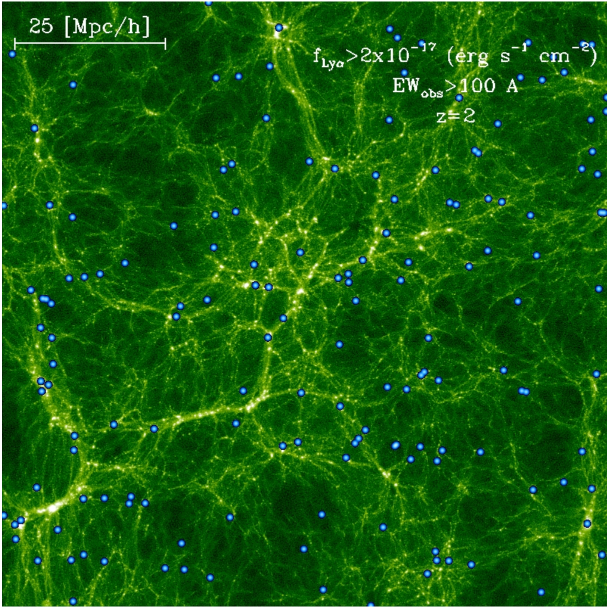
Planting galaxies in the Millennium simulation

N-body haloes		Run **GALFORM**		Galaxies are planted
Mass, positions and velocities are recorded	$\Rightarrow$	Population of galaxies associated with each halo mass	$\Rightarrow$	Central galaxies goes to centre of mass, satellites to randomly selected particles of the halo.

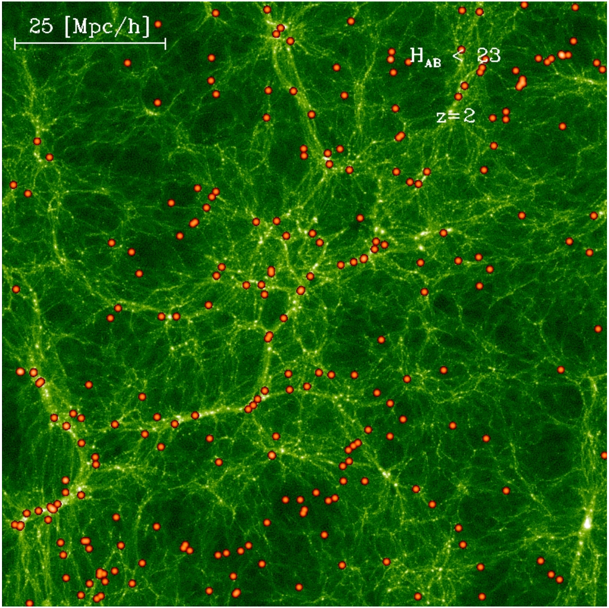
Dark matter at $z = 2$



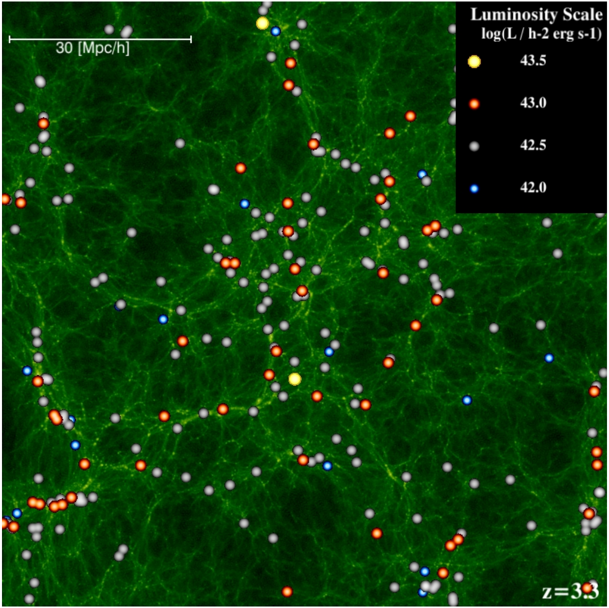
Lyα-emitters at $z = 2$



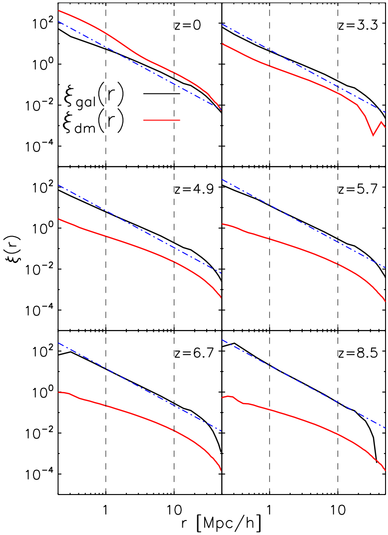
H-band selected sample



Lyα-emitters at $z = 3.3$



The two point correlation function of Lyα emitters

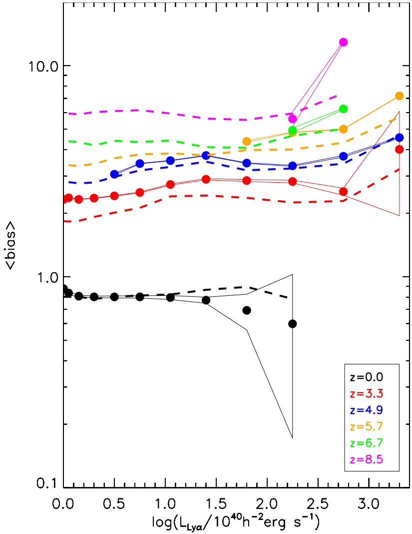


- Deviation from a random distribution:

$$\delta P = n^2 dV_1 dV_2 (1 + \xi(r_{12}))$$

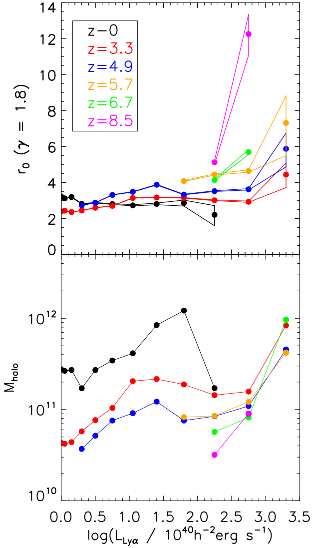
- We study $\xi(r)$ over the redshift interval $0 < z < 9$.
- $\xi_{\rm gal}$ behaves like a power law over a wide range in pair separation.
- $\xi_{\rm gal} = b^2 \xi_{\rm dm}$,,
  b : *effective galaxy bias*.
- $\xi_{\rm dm}$ and $\xi_{\rm gal}$ evolve different with redshift:

Effective bias



- Strong evolution of b with redshift
- Weak dependence on Lyα luminosity.
- Analytic model (dashed lines) approximately reproduces the bias of Lyα emitters for $z < 5$
- Simulation gives more accurate predictions

Correlation length



- $\xi_{\rm gal}$ is a power law $(1 < r < 10h^{-1}Mpc)$

$$\xi(r) = \left(\frac{r}{r_0}\right)^{-\gamma}$$

- r_0 : Correlation length → Amplitude
- At bright luminosities, r_0 evolves with redshift
- Not simple relation between r_0 and $M_{\rm halo}$
- median $M_{\rm halo} \leq 10^{12} M_\odot h^{-1}$ for Lyα emitters

Confronting the model with real data

- Narrow band surveys can be easily simulated to compare them directly with our simulations
- Measure cosmic variance affecting a given survey
- Help designing future experimets

Confronting the model with real data

How we simulate narrow band surveys

- Extract a catalogue of galaxies of a given redshift
- Filter transmission curve $\longrightarrow$ redshift range, flux and EW limits
- Replicate the angular geometry of the real survey
- Degrade to match completeness of the observed sample
- Extract as many mock catalogues as possible from the simulation box

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Measuring clustering

- Narrow band surveys have no 3D information
- angular (projected) correlation function $w(\theta)$ instead

$$w(\theta) = A_w \left(\frac{\theta}{1`} \right)^{-\delta}$$

$$\begin{aligned} \langle w_{LS}(\theta) \rangle &= w(\theta) - w_\Omega \\ w_\Omega &= \frac{1}{\Omega^2} \int d\Omega_1 d\Omega_2 w(\theta_{12}) \end{aligned}$$

- w_Ω: Integral Constraint

Cosmic variance

- For each survey $\sim$ 100 mock catalogues

$\Rightarrow$ Spread in $w(\theta)$

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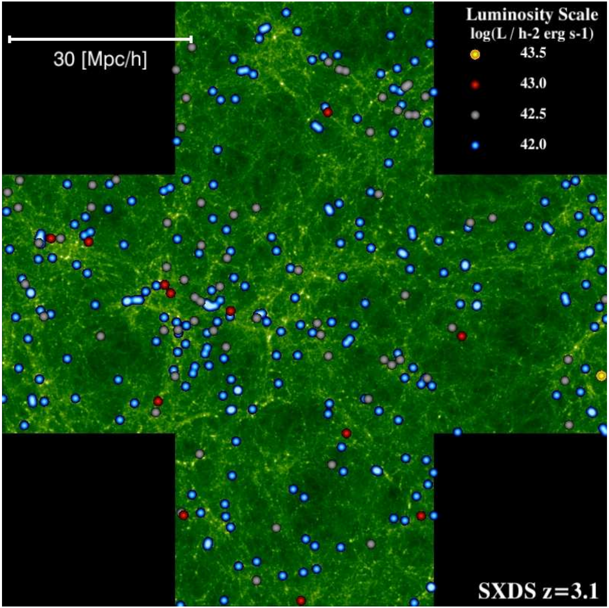
SXDS: Lyα emitters at $3 < z < 6$ *(Ouchi et al. in prep.)*



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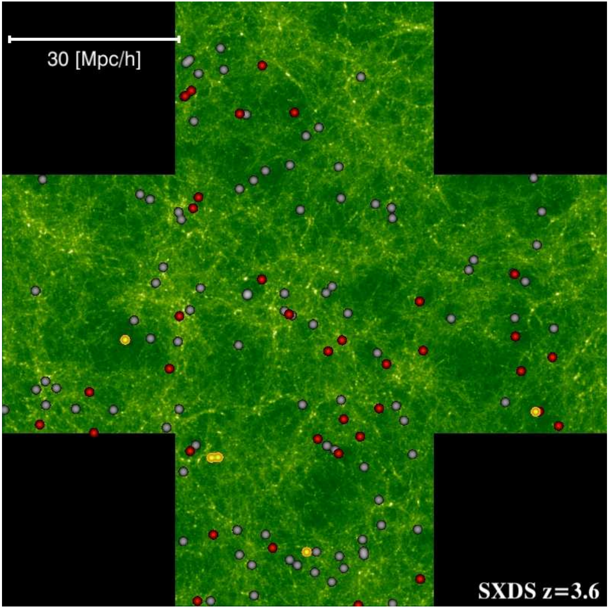

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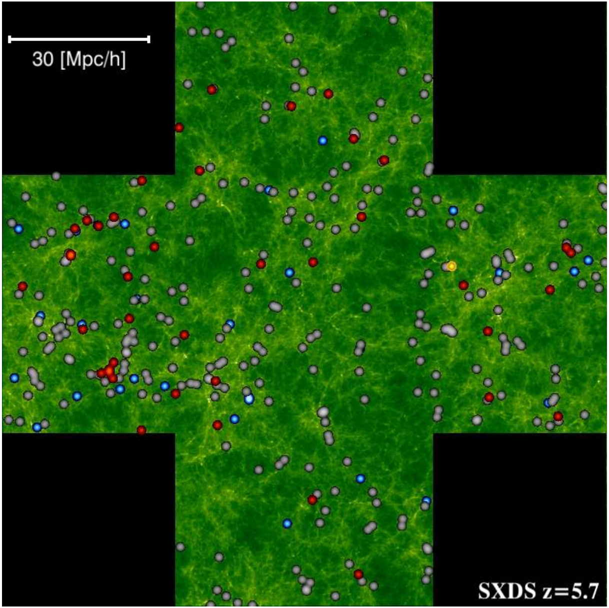

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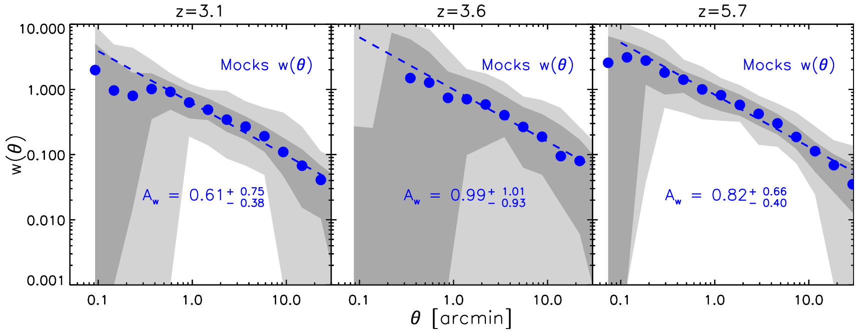

Median ξ_{gal} of mocks

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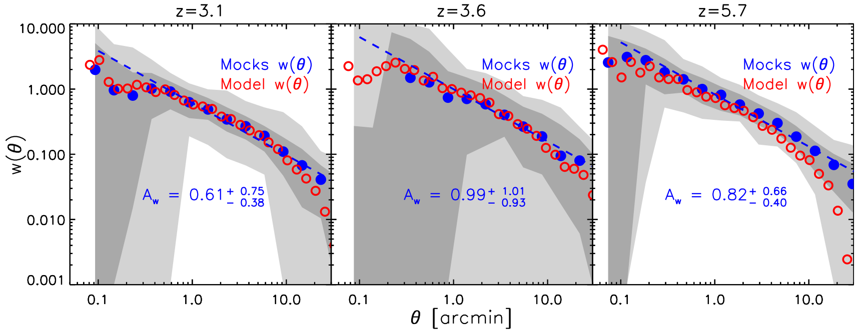

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Idealised survey over much larger solid angle

$\Rightarrow$ median of mocks recover the clustering, but huge scatter between mocks!

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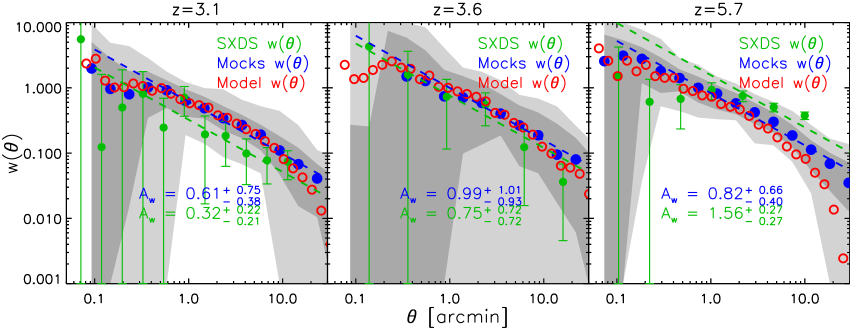

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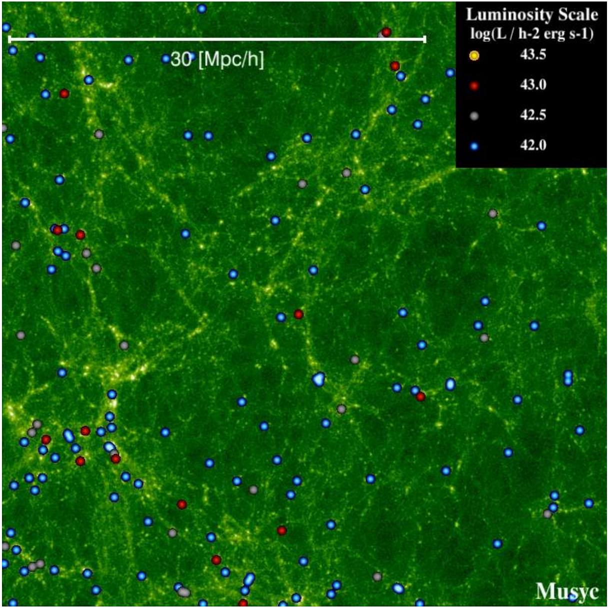
Obervational $\xi_{\rm gal}$

$\Rightarrow$ agrees at 95% confidence

MUSYC Survey, $z = 3.1$



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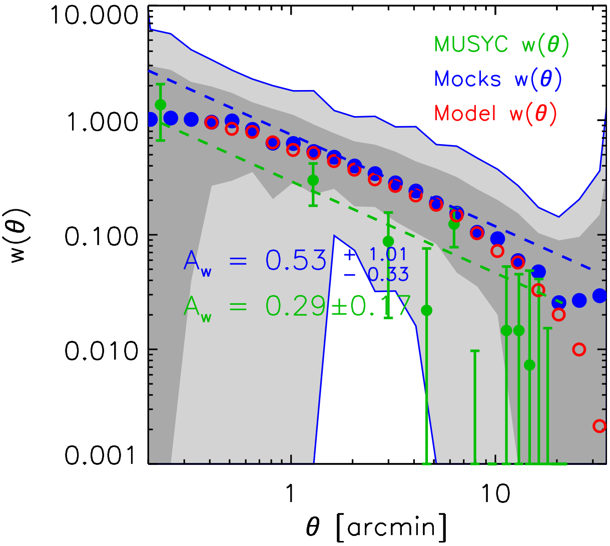
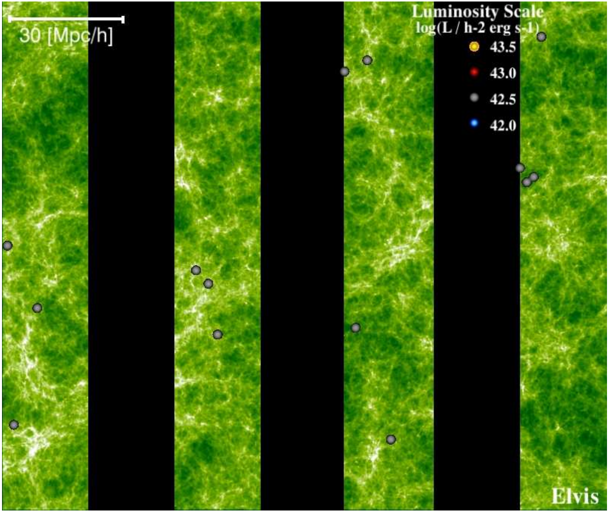


ELVIS, a future survey of Lyα emitters with VISTA at $z = 8.8$

(Nilsson et al. (2007))



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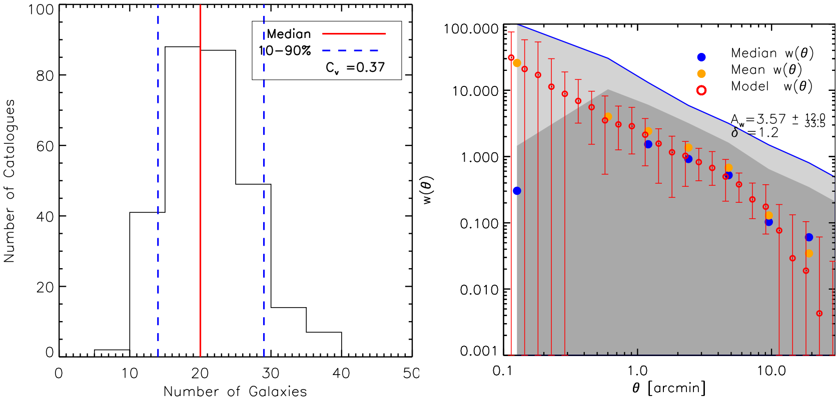

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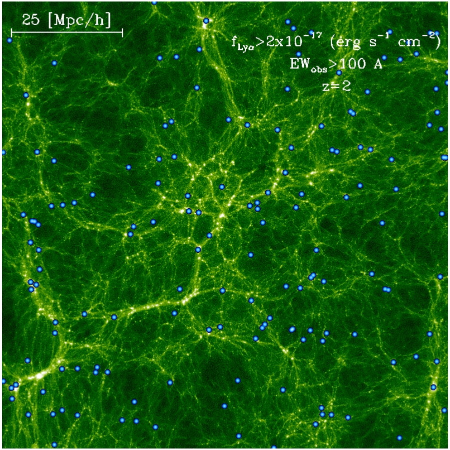
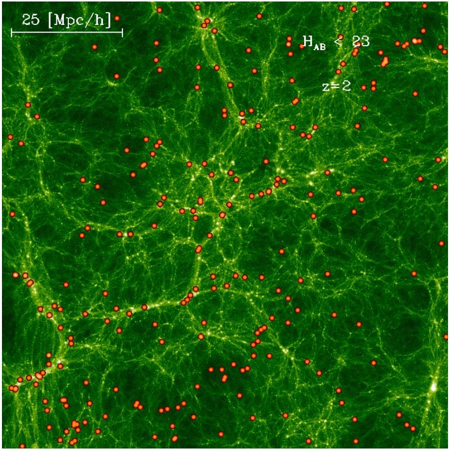
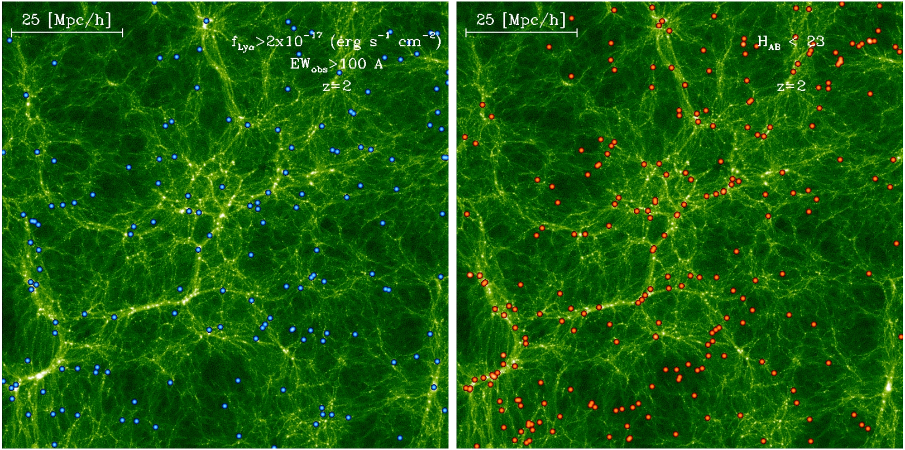
Lyα-emitters vs. H-band selected sample





- Lyα emitters avoid the cores of clusters
- H-band selected galaxies trace massive structures

Lyα-emitters vs. H-band selected sample



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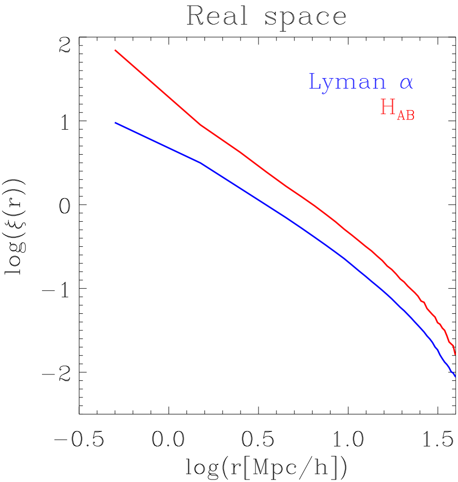
Clustering of Lyα-emitters vs. H-band galaxies



- Real space: Clustering of H_{AB} galaxies is stronger than Lyα-emitters
- Redshift space:
  - Small scales: signal declines due to random velocities
  - Large scales: boost in clustering due to infalling velocities

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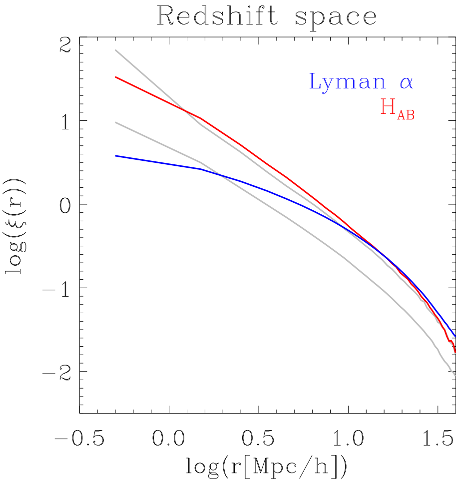

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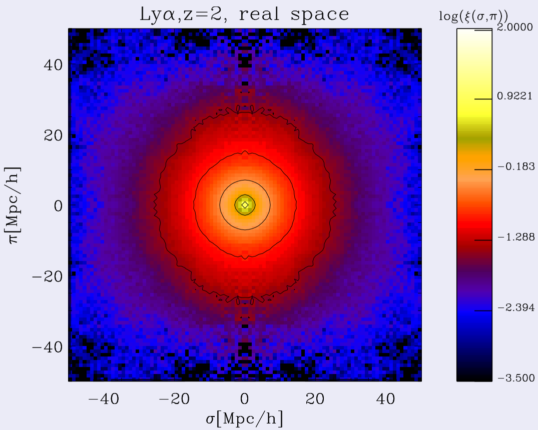
Going further: Redshift space distorsions

Two dimensional correlation function: $\xi(\sigma, \pi)$

Real space: Concentric circles



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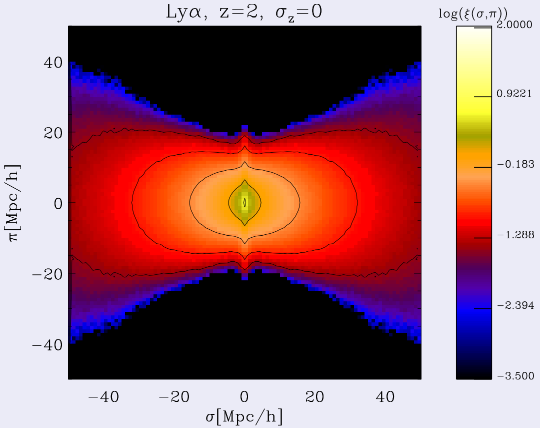
Two dimensional correlation function: $\xi(\sigma,\pi)$

Redshift space: Fingers of god, infalling velocities



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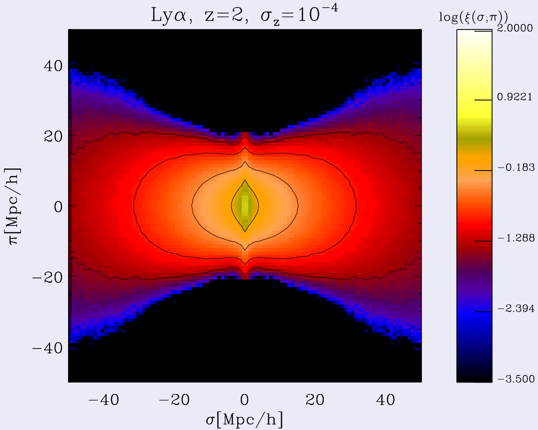
Redshift space + uncertainties in redshift (HETDEX)

$\Rightarrow \sigma_z = 10^{-4}$ has no significant effect on $\xi(\sigma, \pi)$



Going further: Redshift space distorsions

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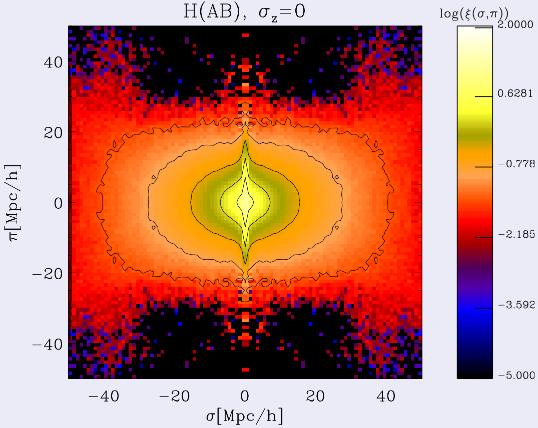
A magnitude limited sample in redshift space: Prominent fingers of god!

$\Rightarrow$ Difficult to model linear redshift distorsions



Conclusions

Evolution of the clustering of Lyα-emitters

- The clustering strength and bias depends strongly on redshift.
- Lyα-emitters avoid the cores of clusters
- Their clustering is weaker than what is found in a magnitude limited sample

Conclusions

Mock catalogues of narrow band surveys

- Observed number of galaxies agrees well with our predictions
- Clustering amplitude agrees well with mocks
- Current surveys have very large sample variance

  $\Rightarrow$ larger samples are needed