# The cosmic web dependence of galaxy clustering

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**Paving the way for next generation of cosmological surveys**

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Sesto, Italy

COSFORM

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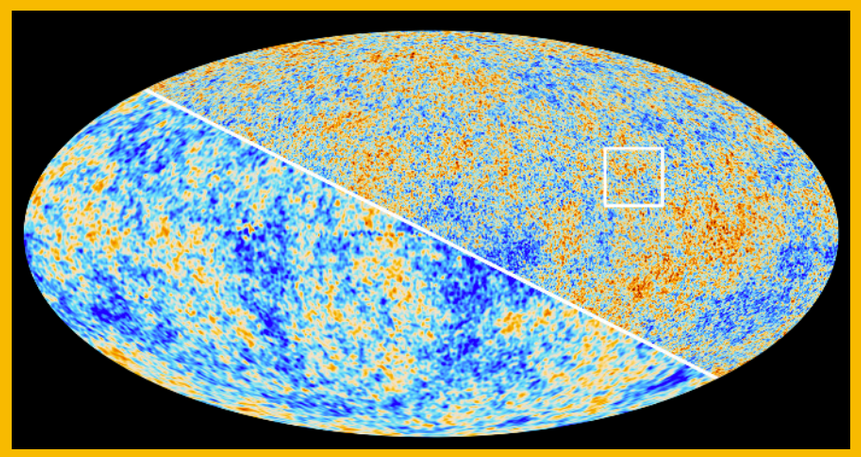
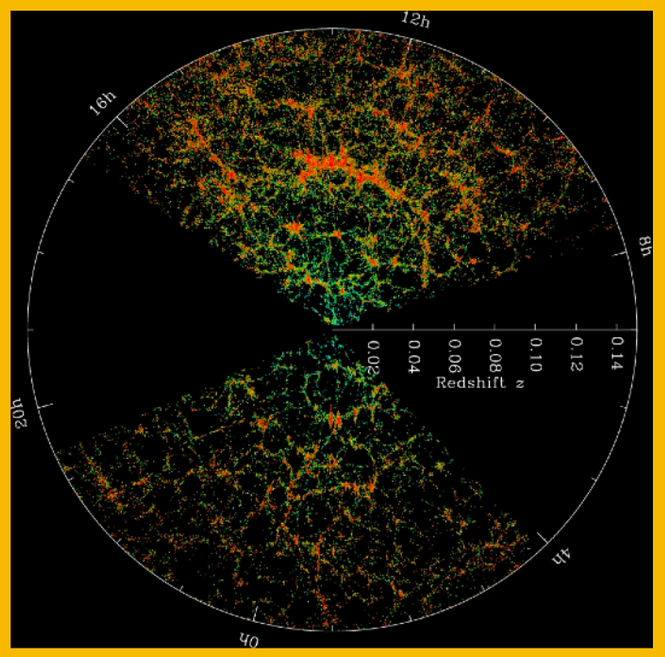
# Modern Cosmology:
## Enigma, Challenges and Visions

**Planck**

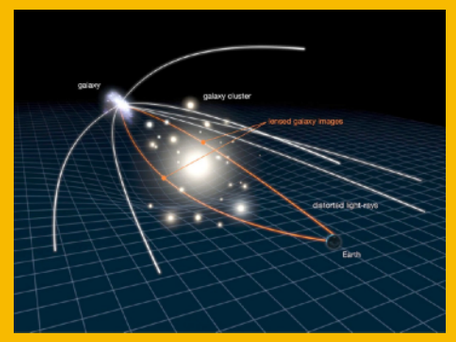


Courtesy: Planck/ESA

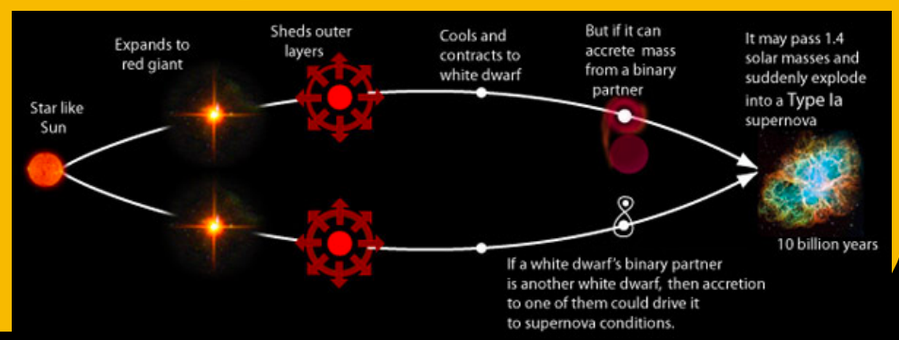
**SDSS**




**Lensing**




**SuperNovae**




| Bary -ons 4.8 | Dark Matter (26.2%) | Dark Energy (69%) |
|---|---|---|

# Scale

**Cosmology-Large Scale Structure**

**Halo Formation**

?

**Galaxy Formation**

**>100 Mpc/h** **~30 Mpc/h** **? Mpc/h** **~0.01 Mpc/h**

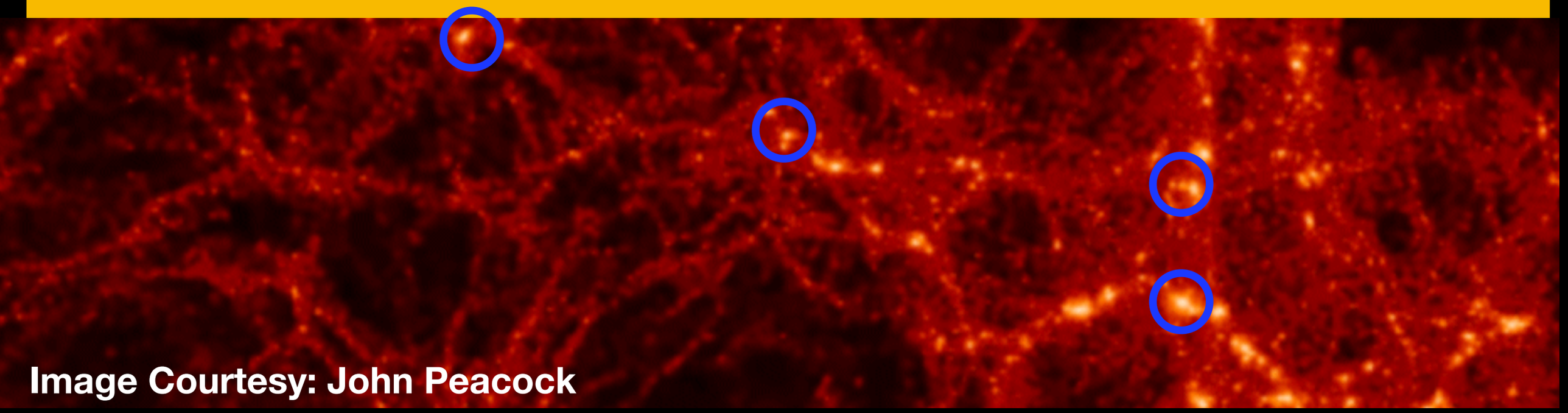
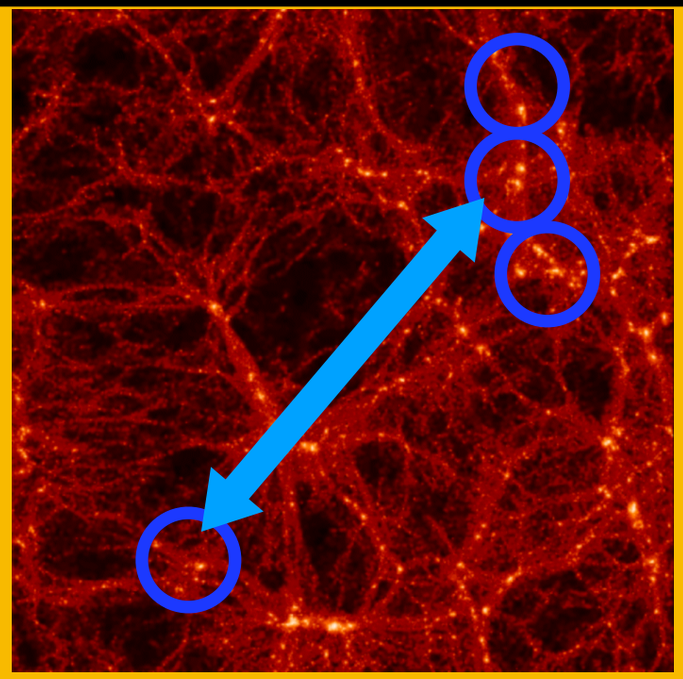


Image Courtesy: John Peacock

# Halo formation

**Dark matter density field**



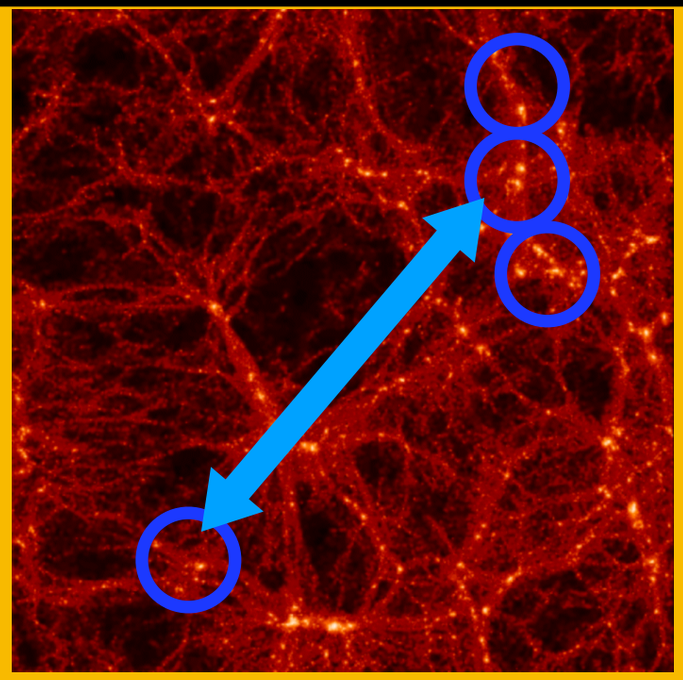
**Gravitational Collapse and growth**

**DM Halos**

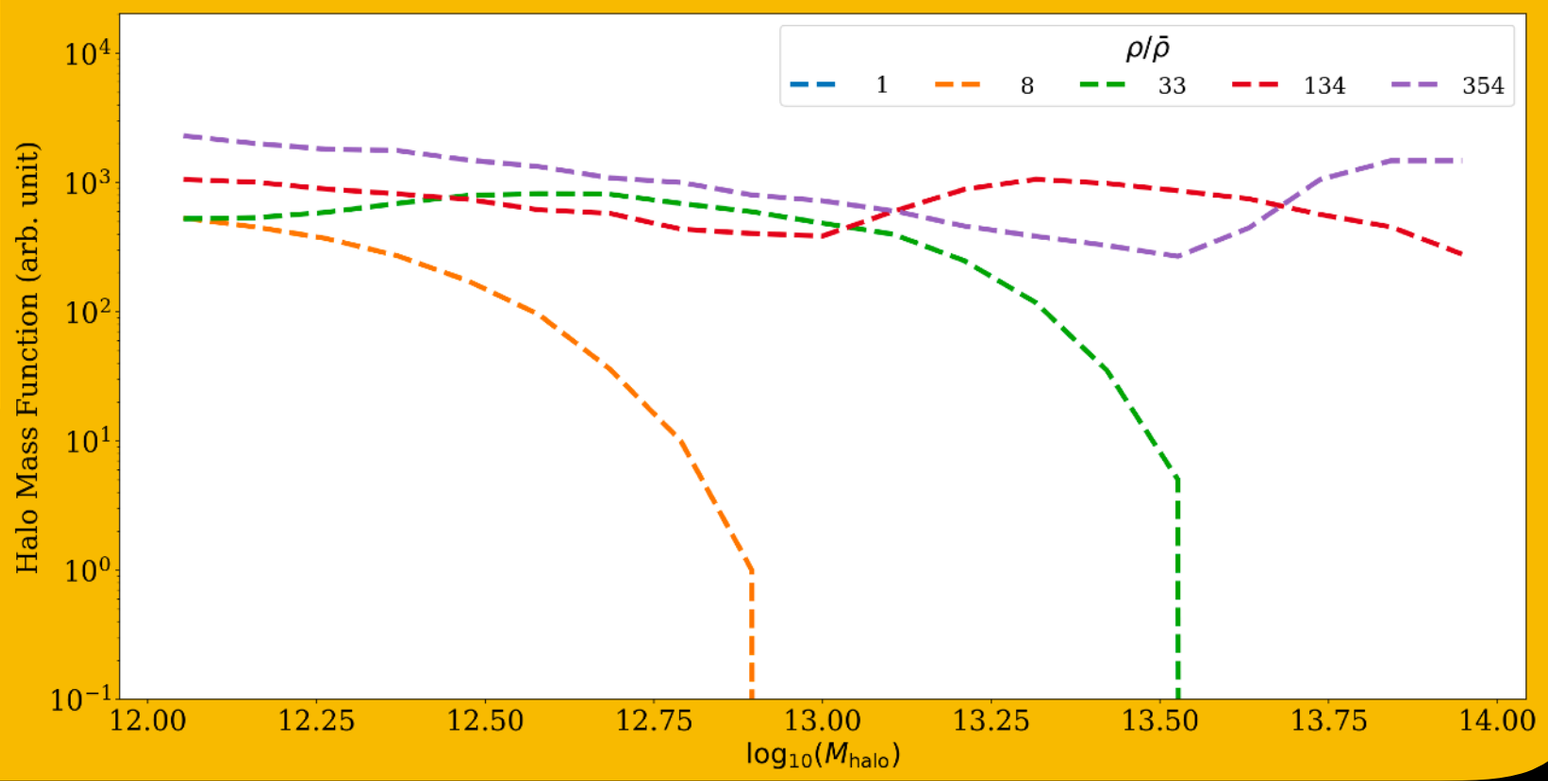
# Halo formation

**Dark matter density field**

**Gravitational Collapse and growth**



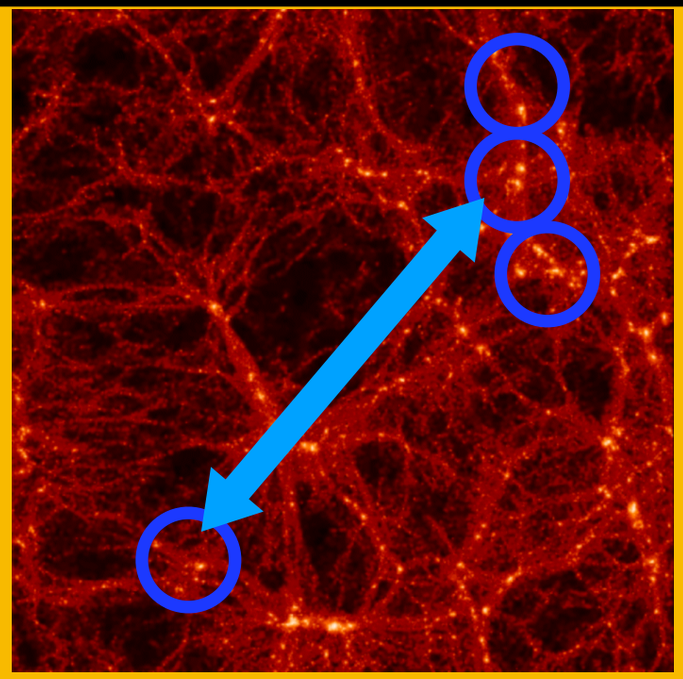
**Solved?**



# Efficient Halo formation?

**Dark matter density field**

**Gravitational Collapse and growth**



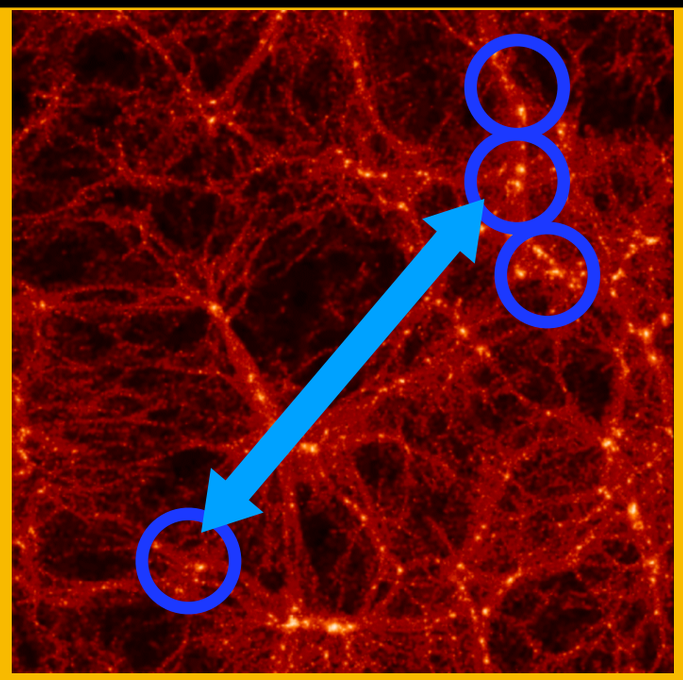
**DM Halos**

**Solved?**

**Minimum properties of density field and halos?**

# Galaxy formation

**Dark matter density field**



**Solved?**

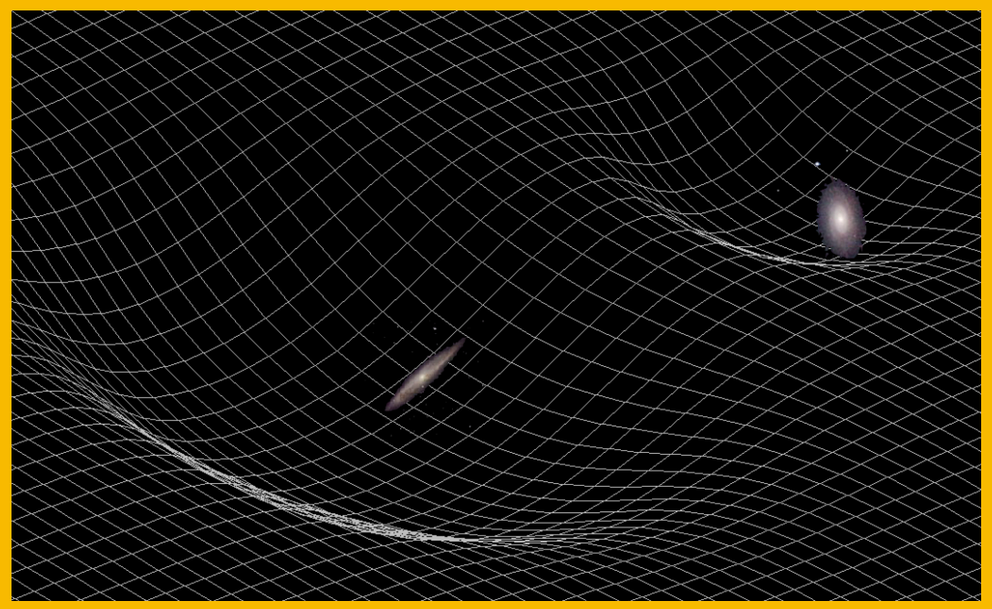
**Gravitational Collapse and growth**

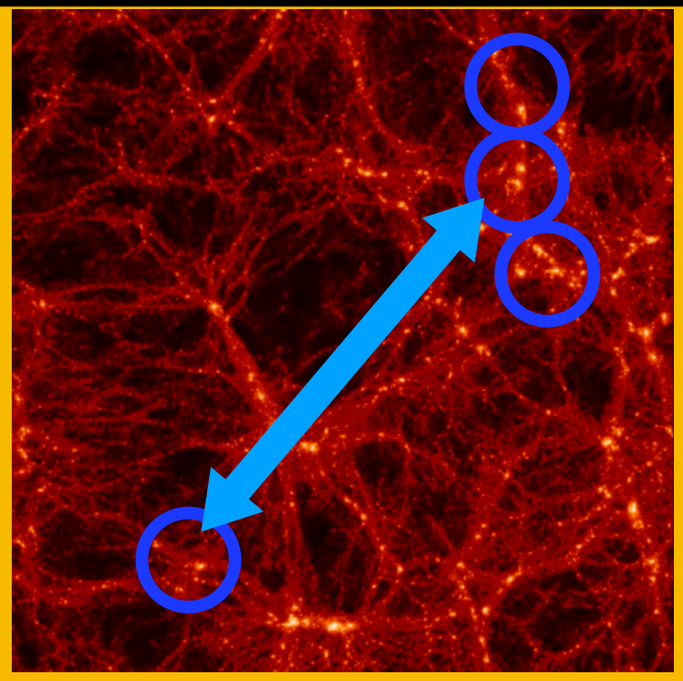
**DM Halos**

**Challenge!!**

**Luminous Galaxies**

# Galaxy formation





**Solved?**

**Halo Mass**

**iHOD?**

**Galaxy Number/colours**

**DM Halos**

**Challenge!!**

**Luminous Galaxies**

# Frame work

**Data:**

**SDSS Main Galaxy sample**

**redsfhit <0.074**

**Stellar Mass > 10^11**

**Massive Galaxies**

**Model:**

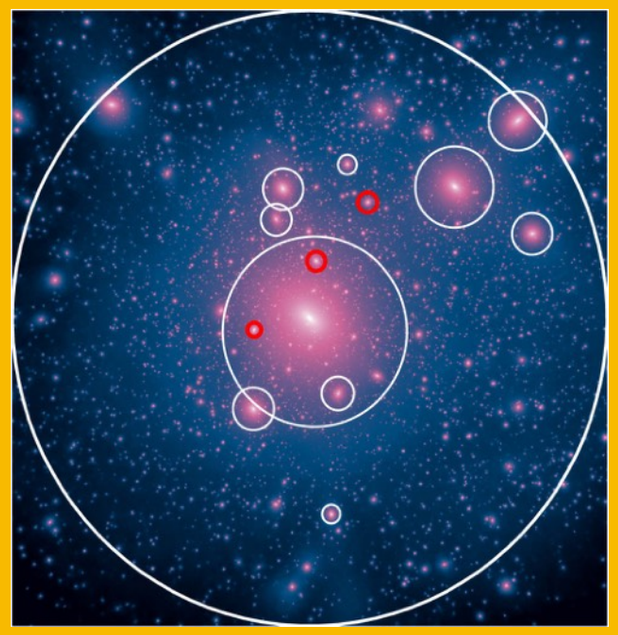
**Dark Matter only Nbody simulation**

**iHOD:**

**Halo Mass determines galaxy properties**

# Halo Occupation Distribution (HOD)

## Dark matter halo



**Halo mass**

**Over-density**

$$\delta = \frac{\rho}{\bar{\rho}} - 1$$

$$b(M_{\rm halo})$$

$$\langle N(M)\rangle = \langle N_{\rm cen}(M)\rangle\,(1 + \langle N_{\rm sat}(M)\rangle)\,,$$

$$\langle N_{\rm cen}(M)\rangle = \frac{1}{2}\left[1 + {\rm erf}\left(\frac{\log M - \log M_{\rm min}}{\sigma_M}\right)\right],$$

$$\langle N_{\rm sat}(M)\rangle = \left(\frac{M - M_0}{M_1'}\right)^{\alpha},$$

# Halo Occupation Distribution (HOD)

## Dark matter halo

**Halo environments**

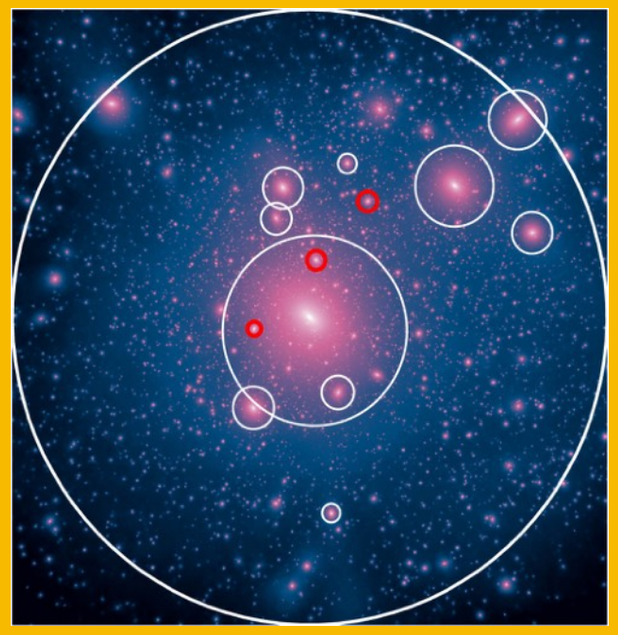
**Tidal environment**

**Redshift of formation**

**Galaxy formation**

**Assembly Bias**

$$b(M_{\rm halo}, z_f, \alpha)$$



**Halo mass**

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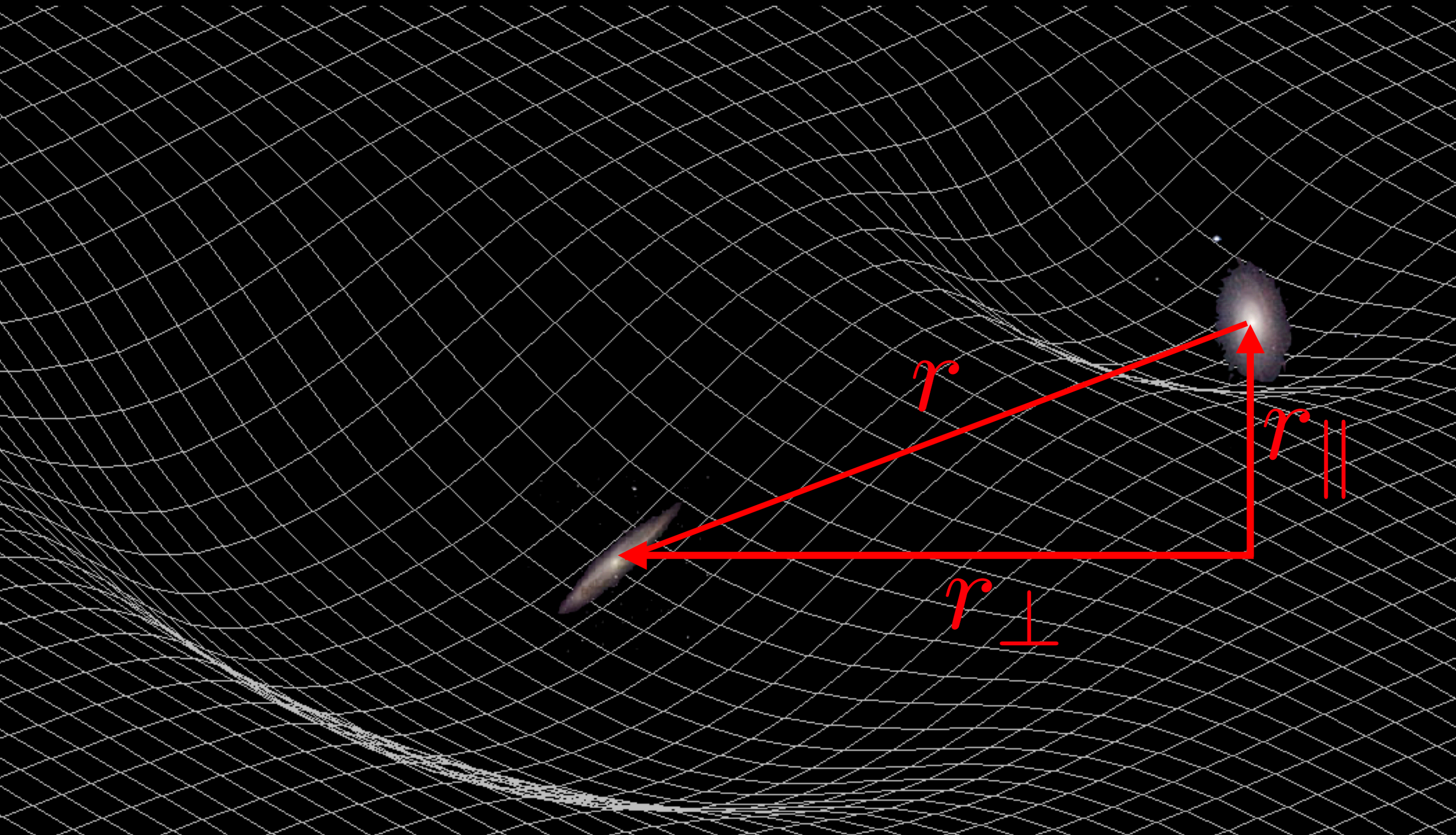
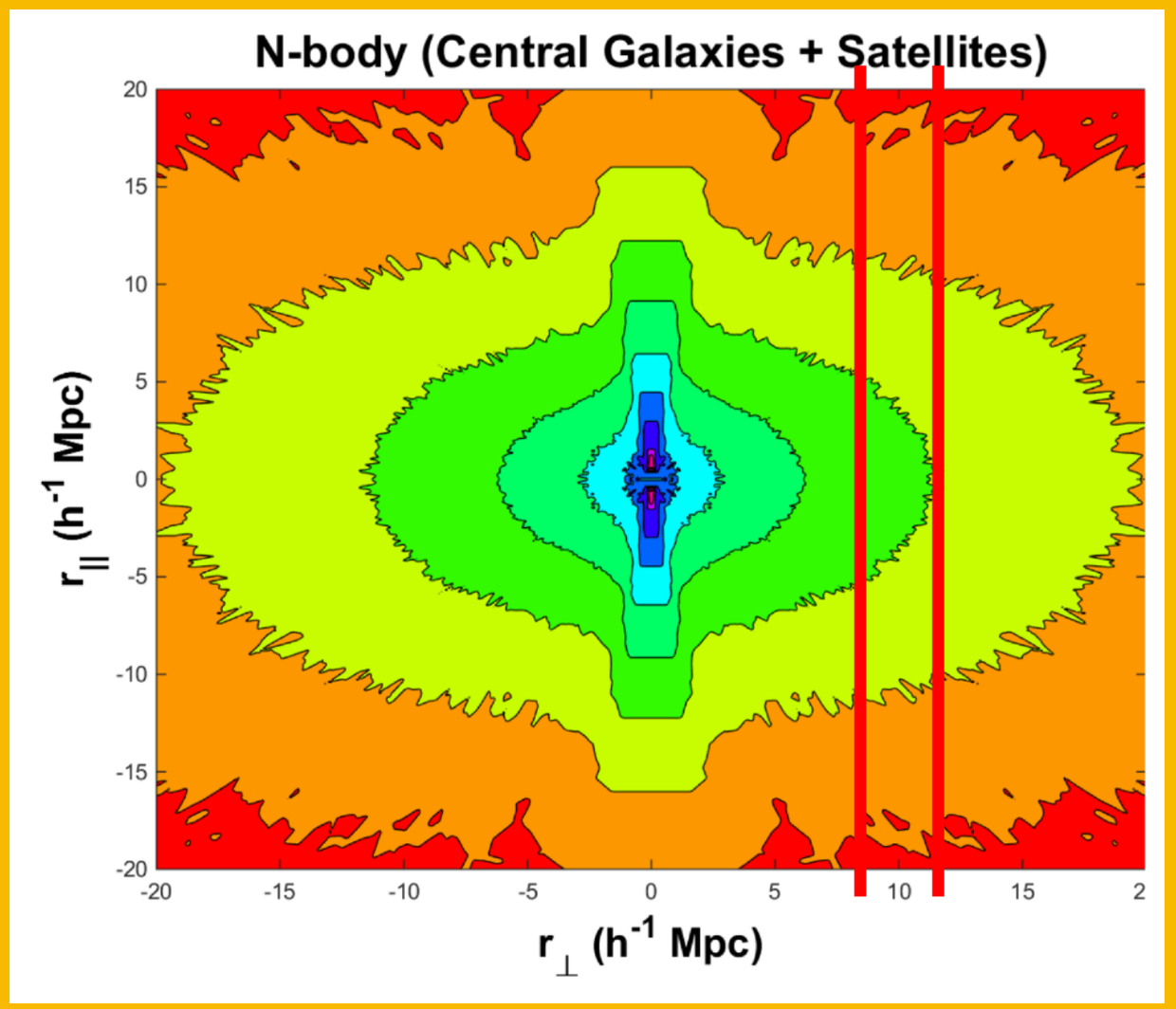
# Two-Point Correlation Function

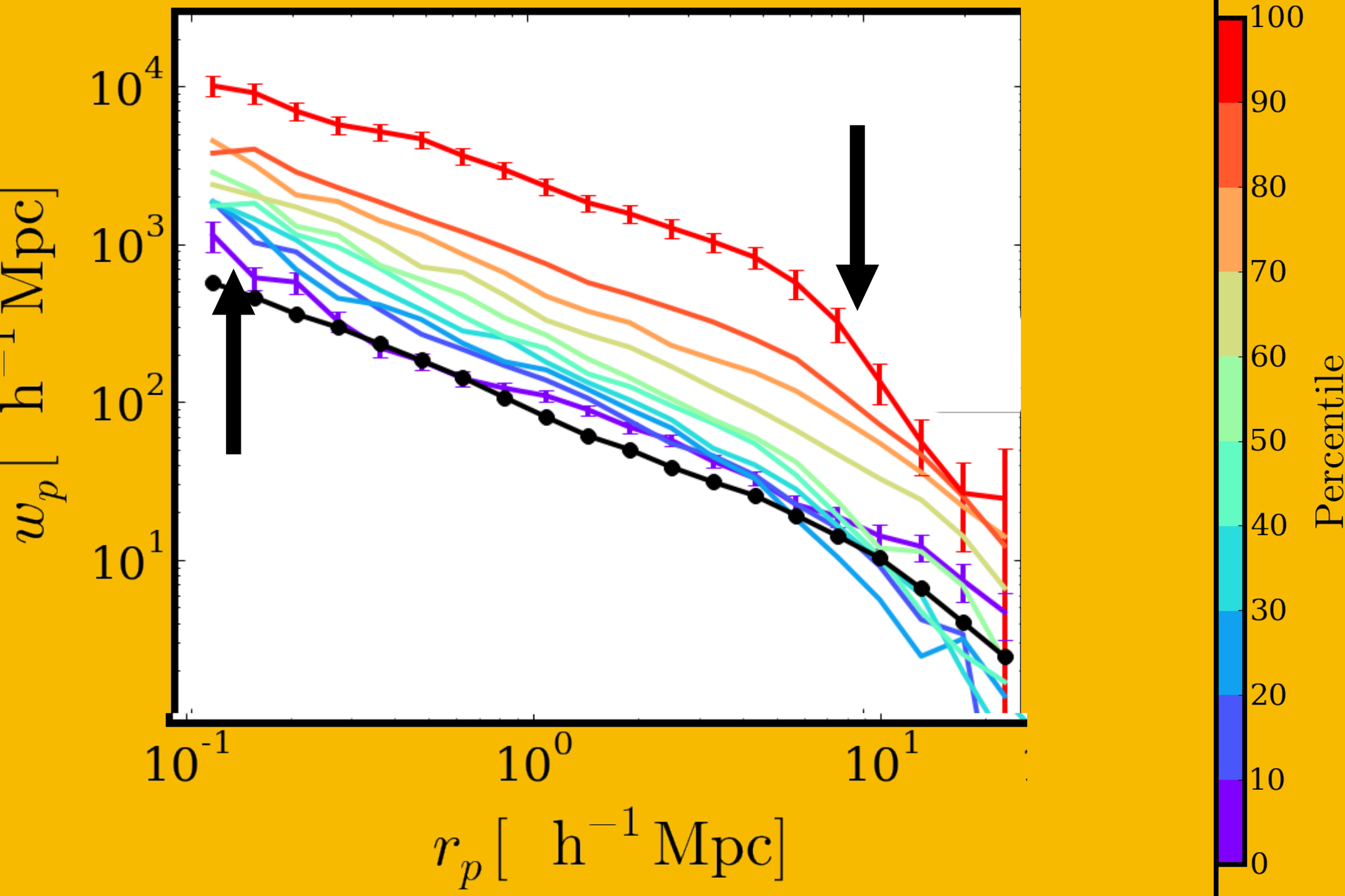


# Projected Correlation fn.

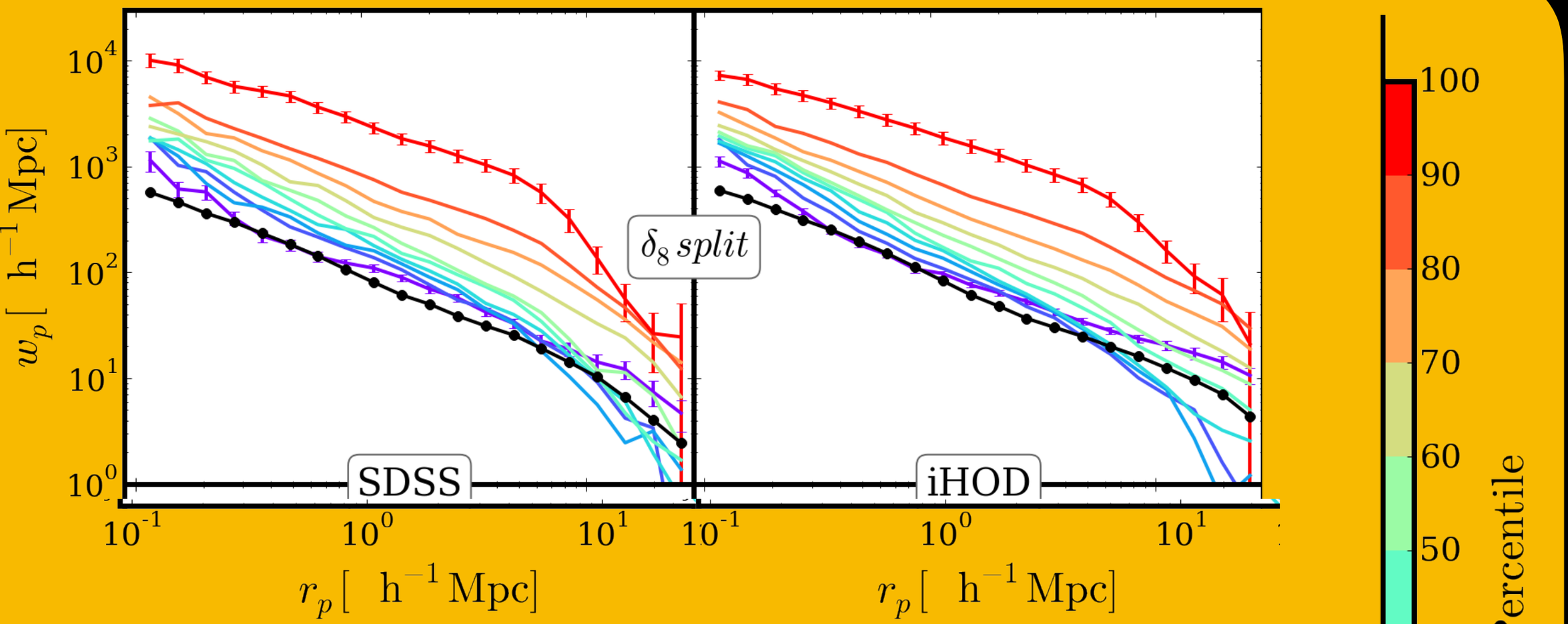
$$w_p(r_p) = \int_{-\Pi}^{\Pi} \xi(r_{\parallel}, r_{\perp}) dr_{\parallel}$$



# Projected Correlation function (SDSS)



# Halo formation effect?



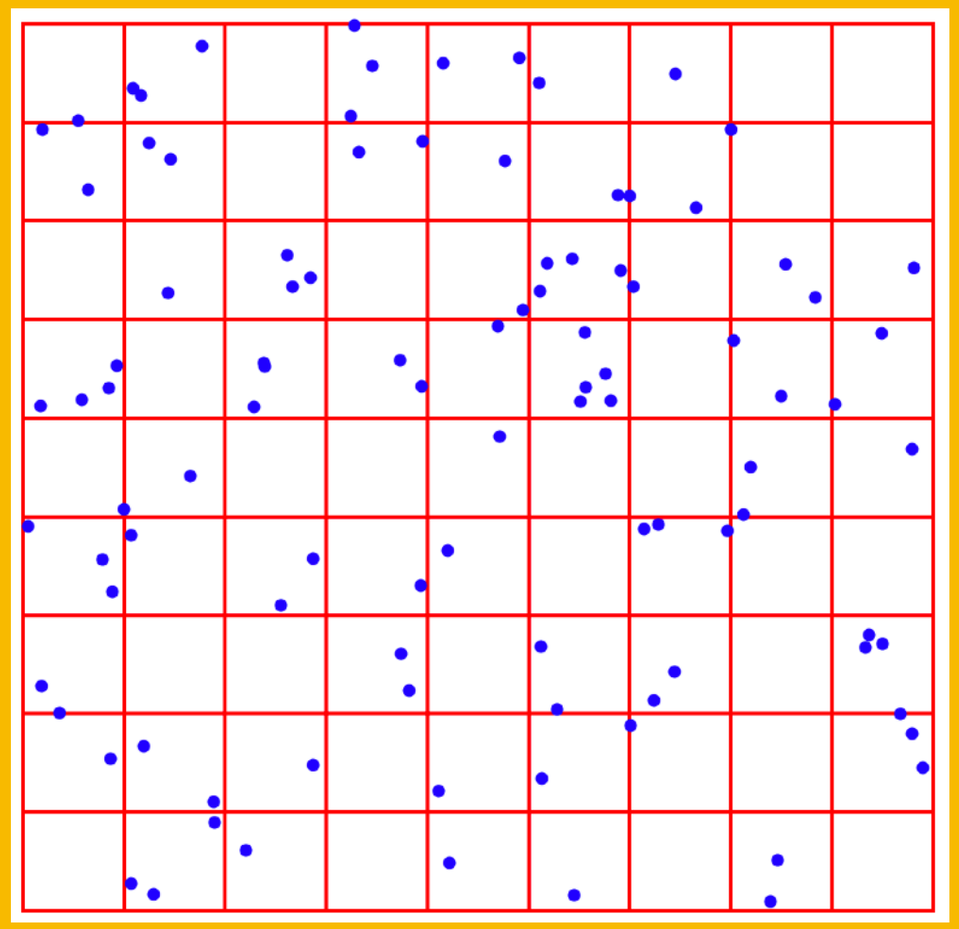

**Over-density: Primary environment dominates halo formation. No signature for galaxy formation physics for LRG.**

**Secondary Environment?**

# Tidal Environment

**Count number of galaxies in a cell**

$$\delta_g^r = \frac{\rho_g}{\bar{\rho}_g} - 1 \quad \xrightarrow{\text{FFT}} \quad \delta_g^k$$



**Tidal Tensor:**

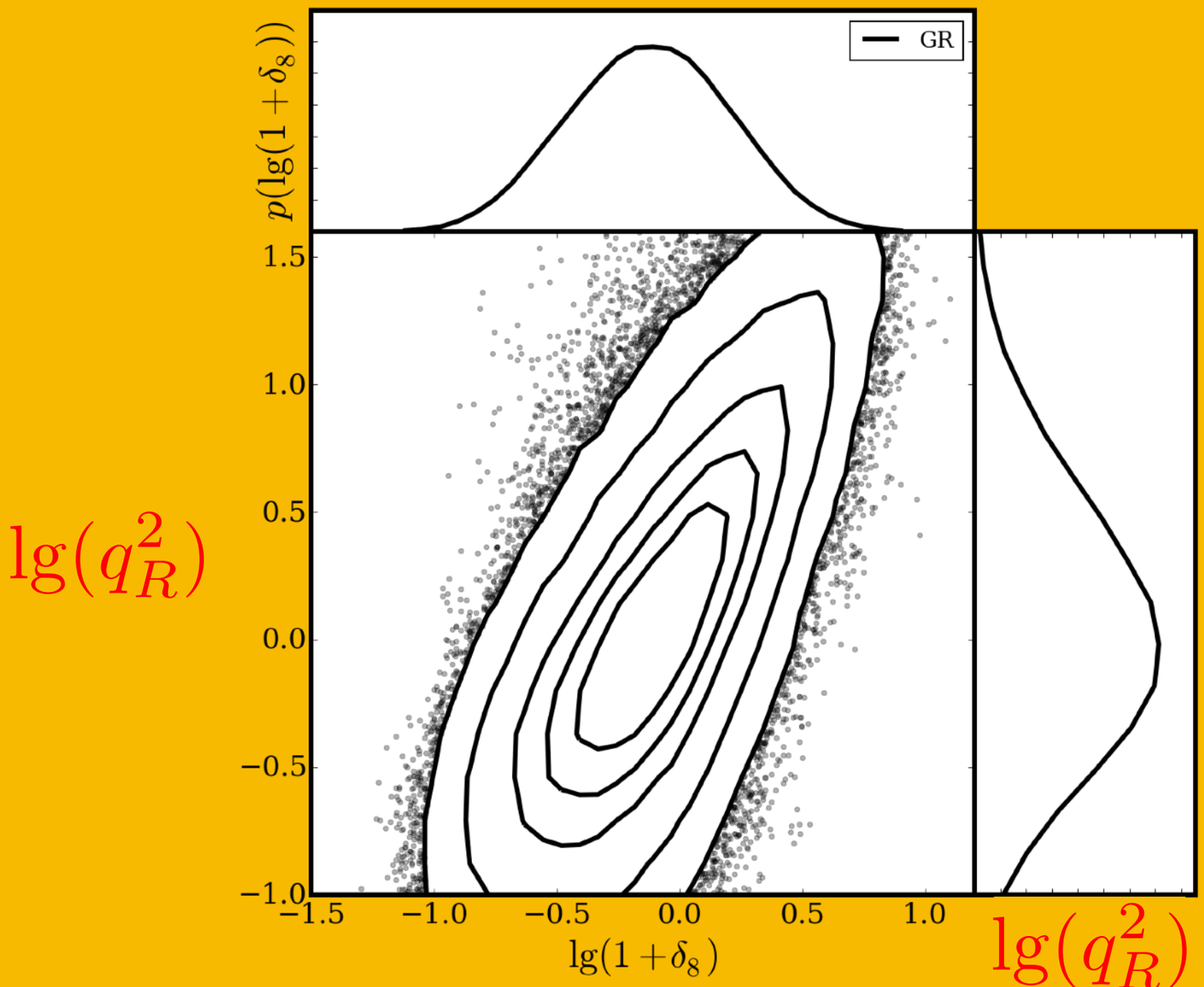
$$\tilde{T}_{ij}^k = \frac{\partial^2 \tilde{\Phi}^k}{\partial_i \partial_j} = \frac{k_i k_j \delta_g^k}{k^2}$$

FFT

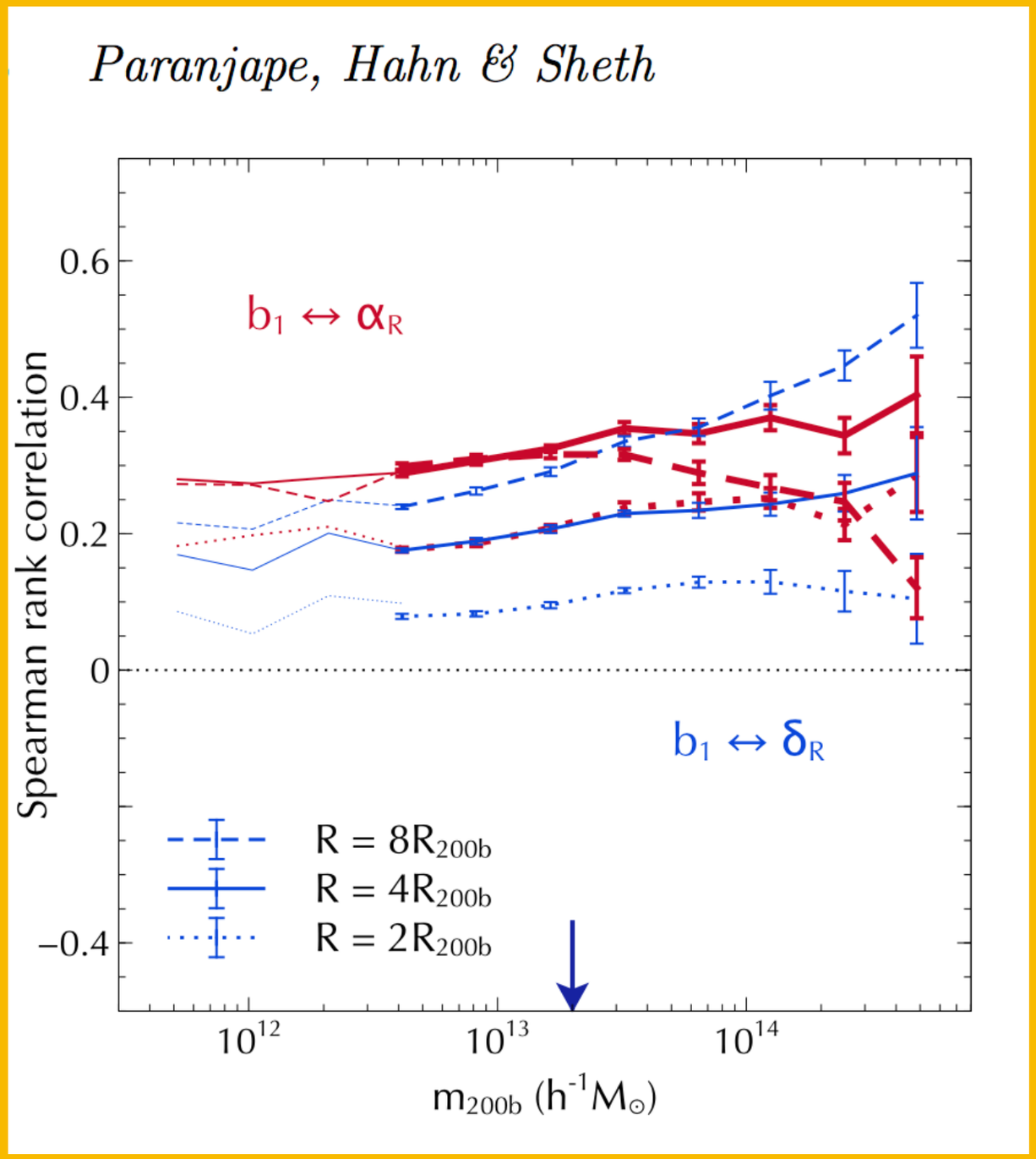
$$\tilde{T}^s = \begin{bmatrix} \partial^2\tilde{\Phi}/\partial x^2 & \partial^2\tilde{\Phi}/\partial x\partial y & \partial^2\tilde{\Phi}/\partial x\partial z \\ \partial^2\tilde{\Phi}/\partial y\partial x & \partial^2\tilde{\Phi}/\partial y^2 & \partial^2\tilde{\Phi}/\partial y\partial z \\ \partial^2\tilde{\Phi}/\partial z\partial x & \partial^2\tilde{\Phi}/\partial z\partial y & \partial^2\tilde{\Phi}/\partial z^2 \end{bmatrix}. \quad \xrightarrow{\text{Eigen values}} \quad \lambda_1,\ \lambda_2,\ \lambda_3$$

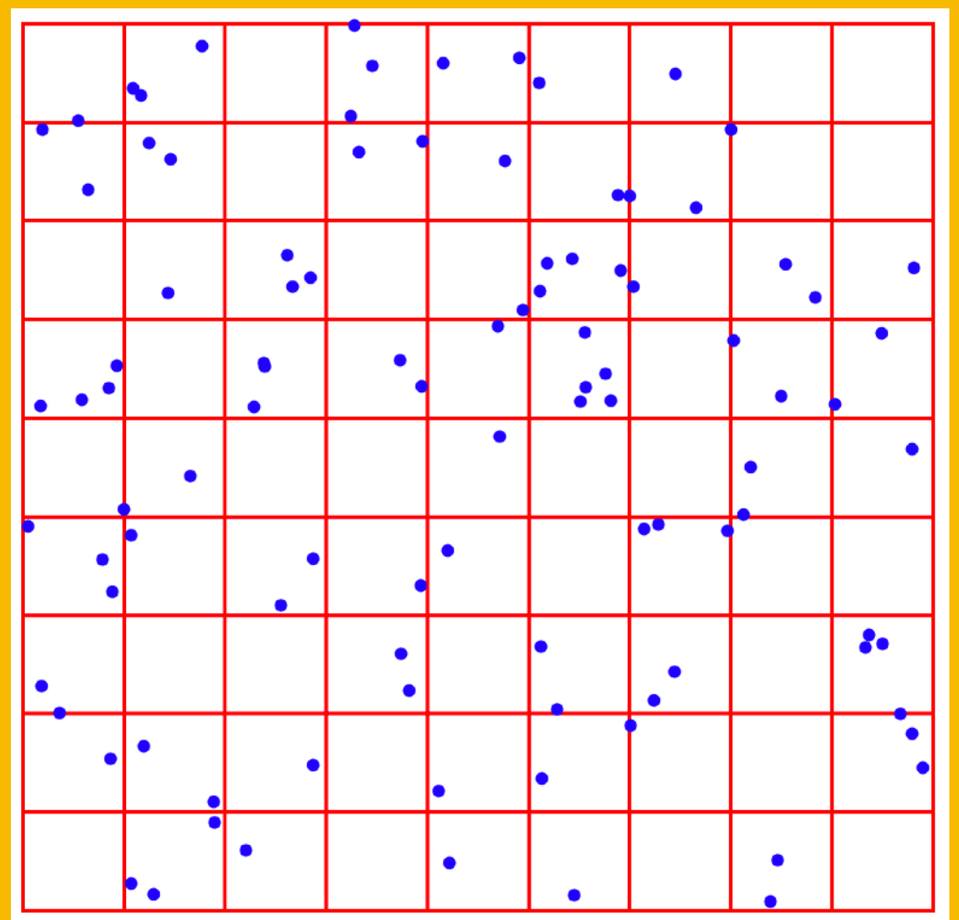
# Tidal Shear

$$q_R^2 = \frac{1}{2}[(\lambda_3 - \lambda_2)^2 + (\lambda_3 - \lambda_1)^2 + (\lambda_2 - \lambda_1)^2]$$



# Tidal anisotropy



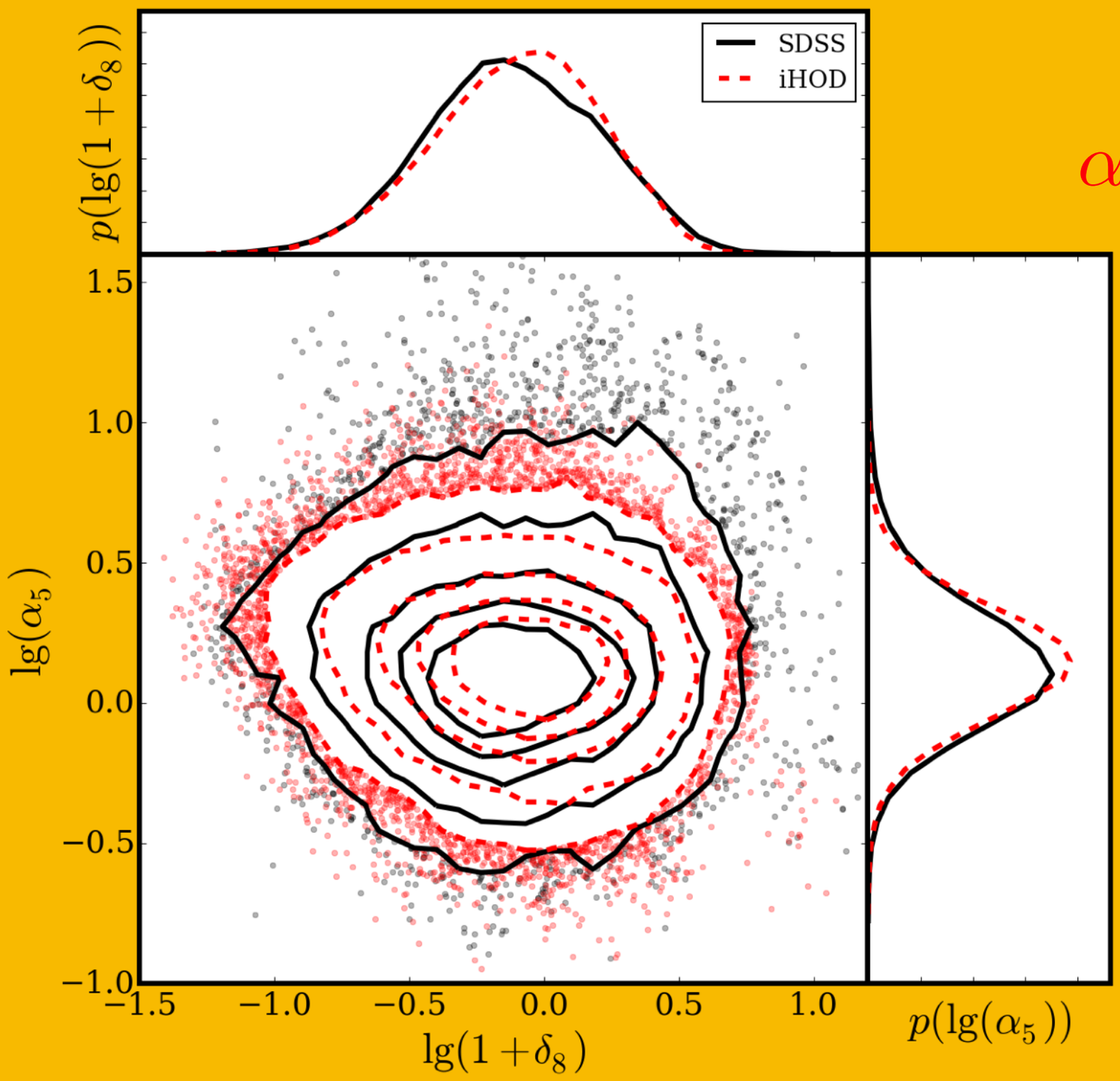



$$\alpha_R \equiv \sqrt{q_R^2}(1+\delta_R)^{-n}$$

$$n = 1$$

Aseem Paranjape, Oliver Hahn, Ravi Sheth, arXiv:1706.09906

# Tidal anisotropy

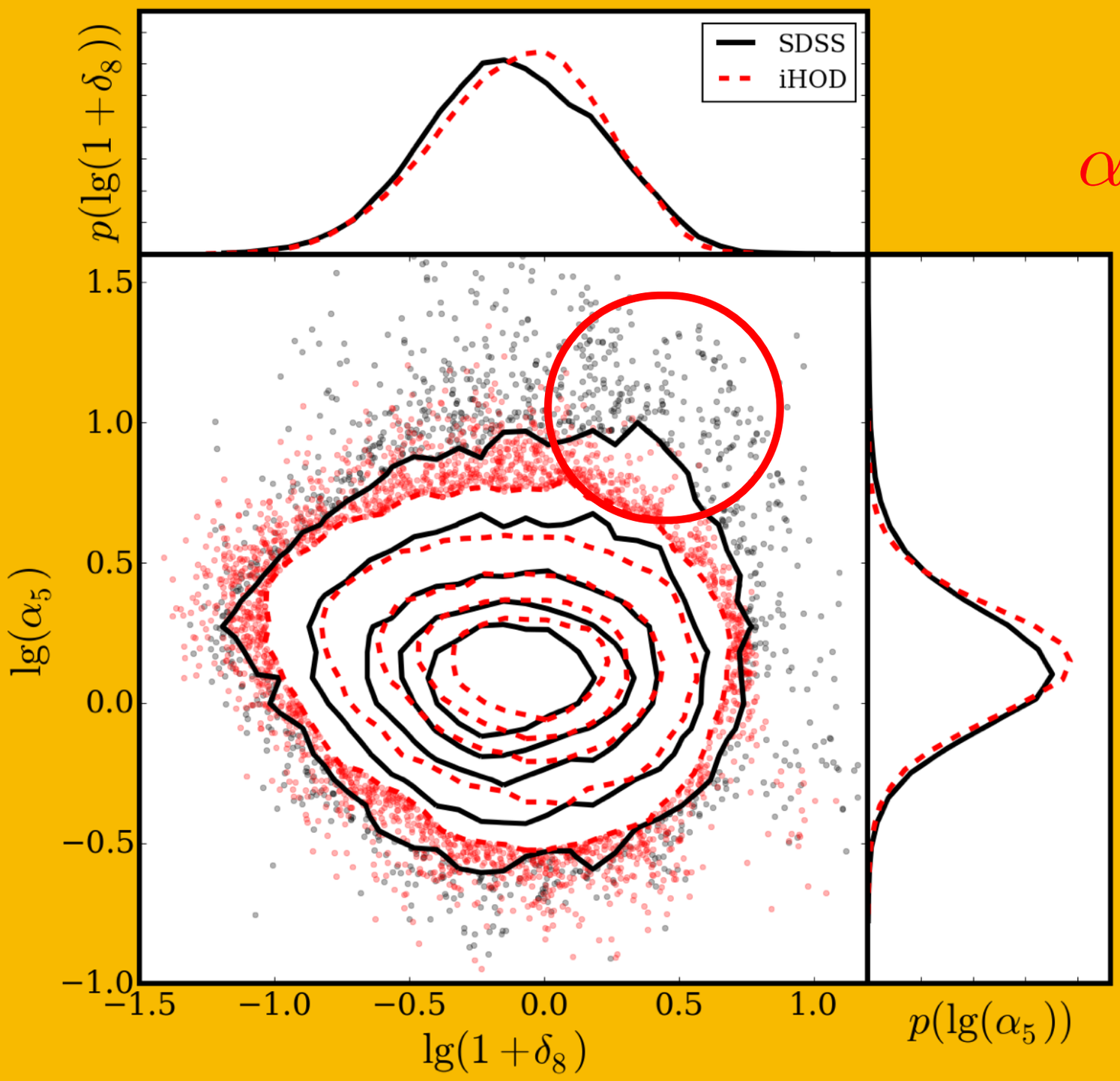



$$\alpha_R \equiv \sqrt{q_R^2}(1+\delta_R)^{-n}$$

$$n = 0.55$$

Shadab Alam, Ying Zu, John Peacock, Rachel Mandelbaum, arXiv:1801.04878

# Tidal anisotropy

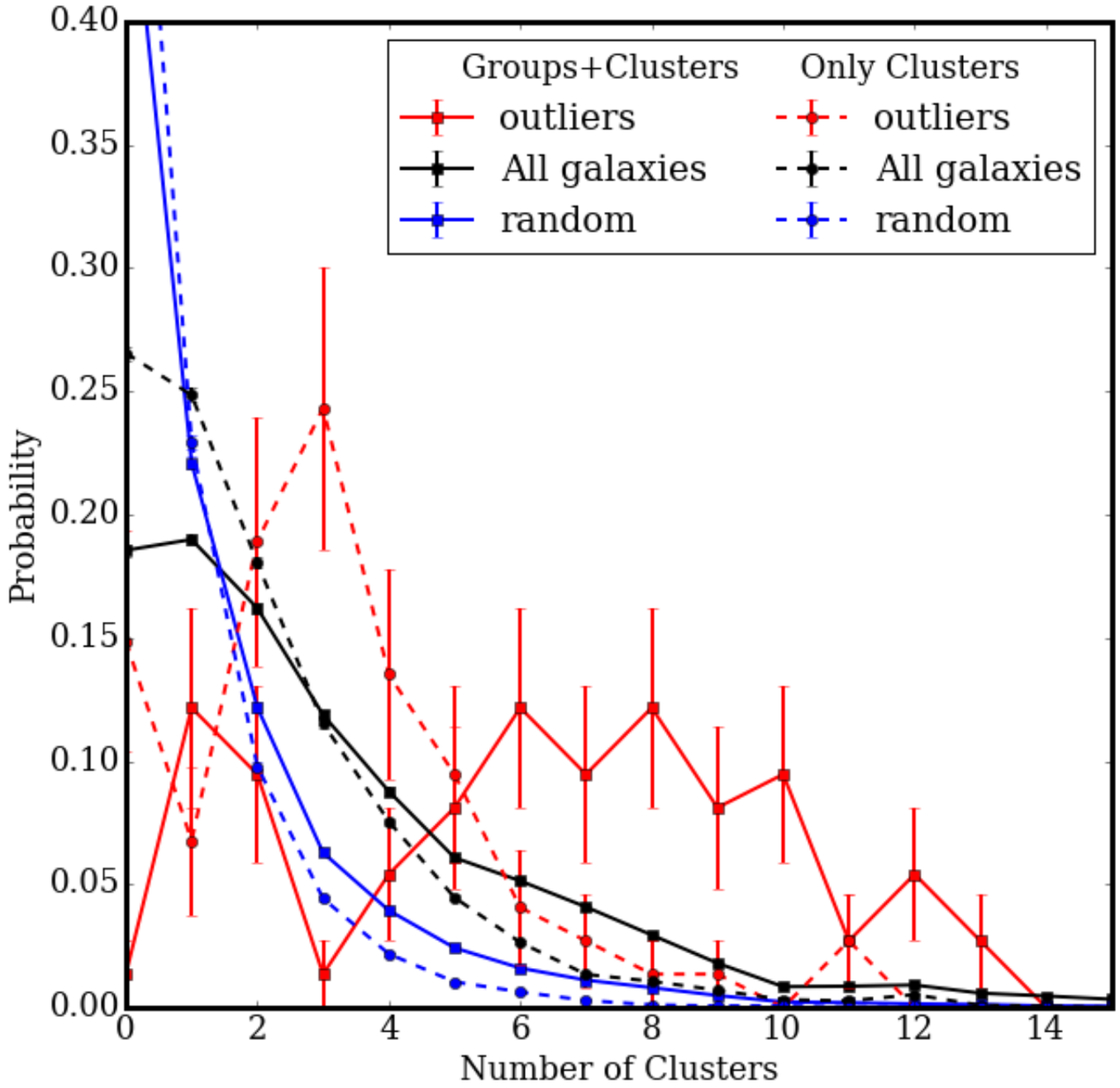



$$\alpha_R \equiv \sqrt{q_R^2}(1+\delta_R)^{-n}$$

$$n = 0.55$$

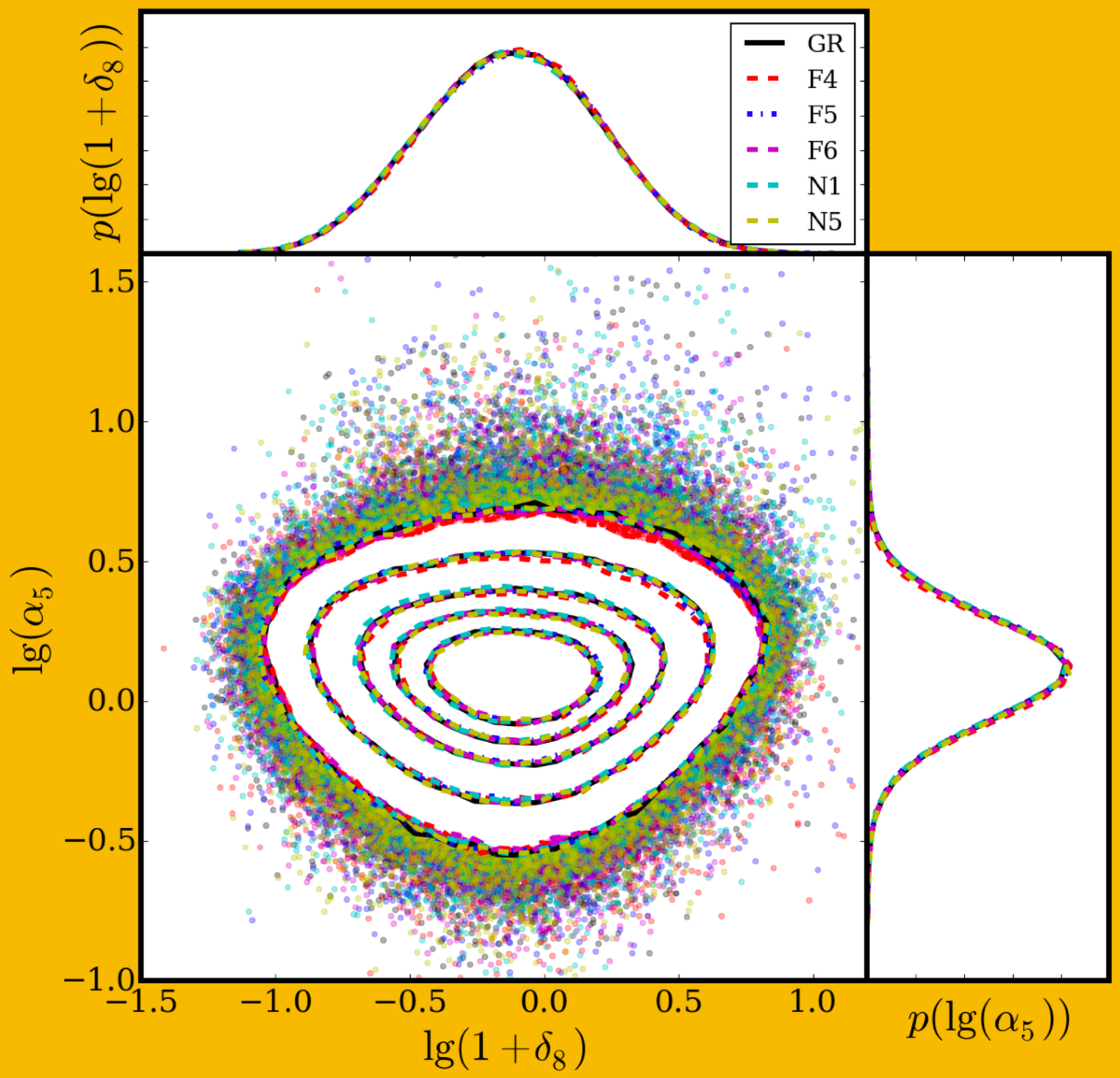
Shadab Alam, Ying Zu, John Peacock, Rachel Mandelbaum, arXiv:1801.04878

# Possible Super Cluster




Shadab Alam, Ying Zu, John Peacock, Rachel Mandelbaum, arXiv:1801.04878

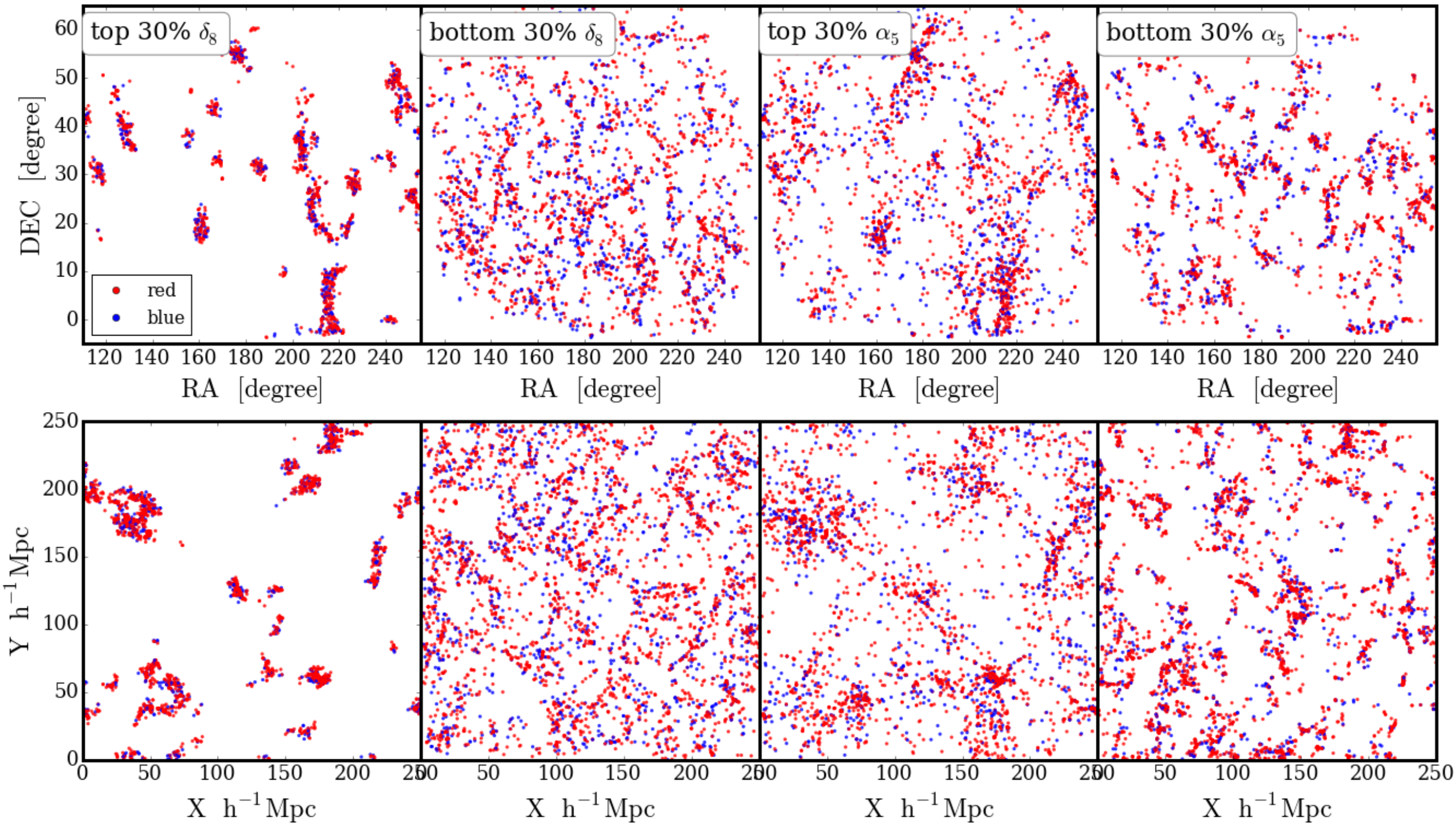
# Tidal anisotropy (Universal?)



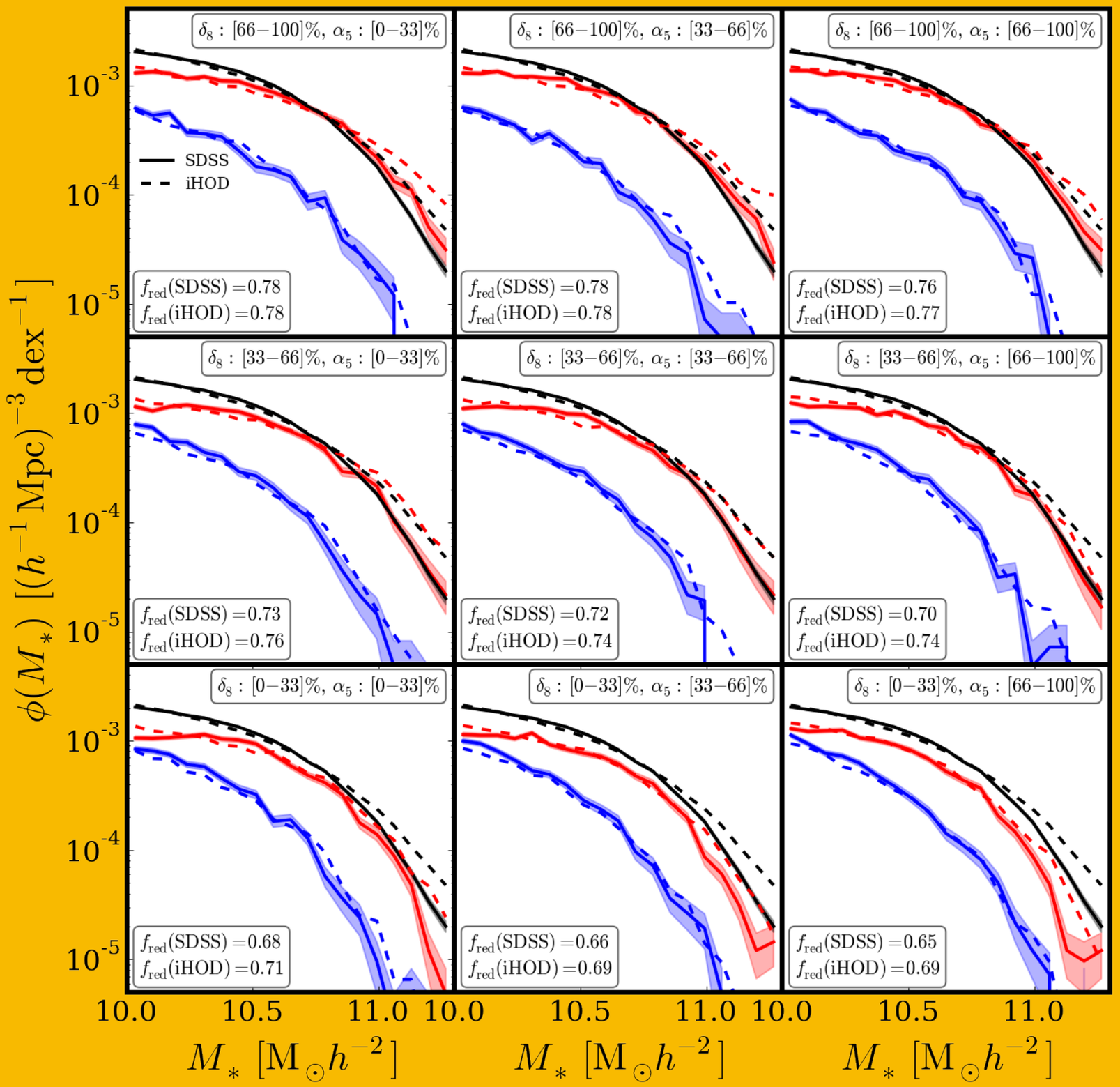

$$\alpha_R \equiv \sqrt{q_R^2}(1+\delta_R)^{-n}$$

$$n = 0.55$$

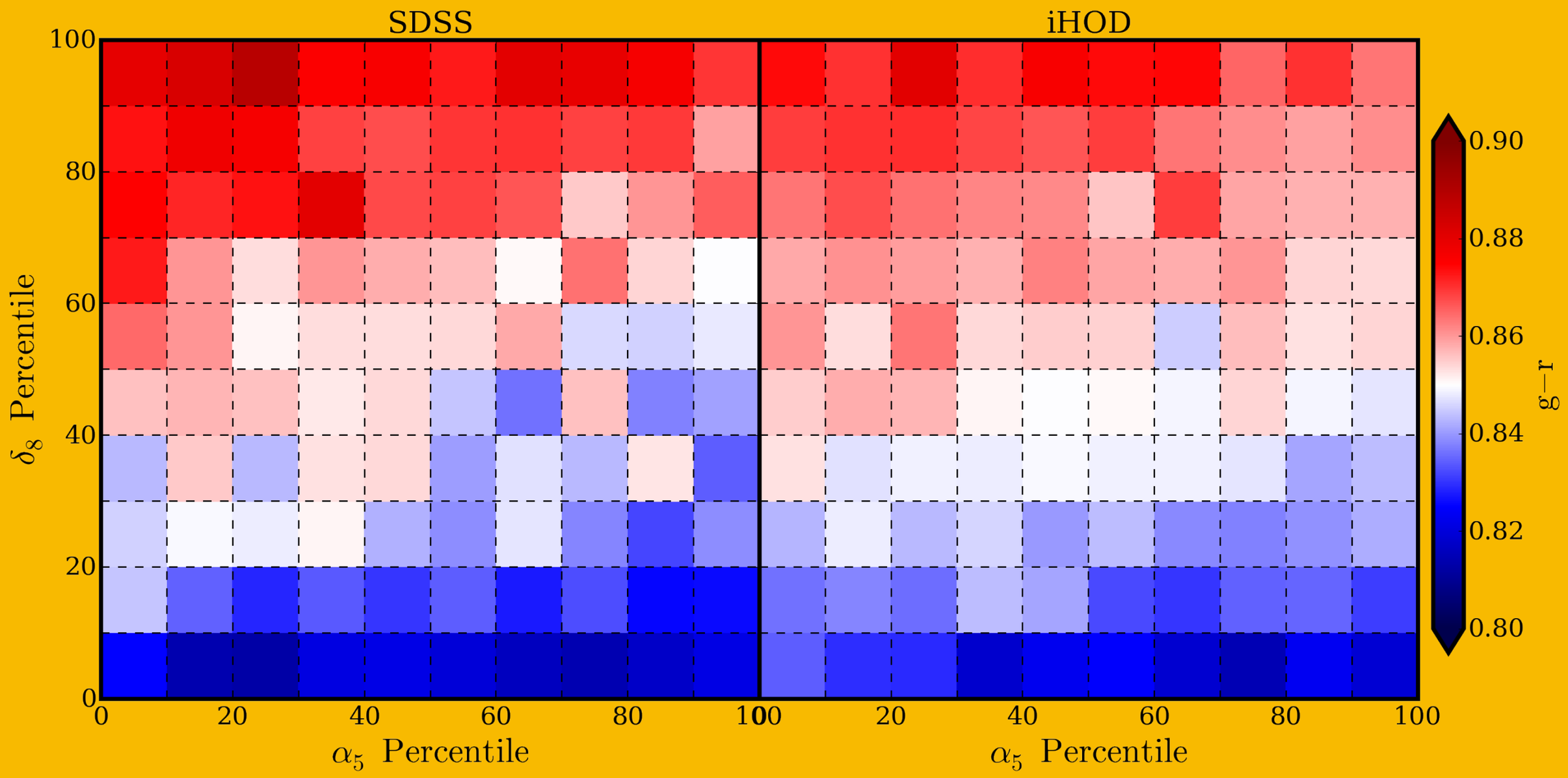
# Galaxy in different environments



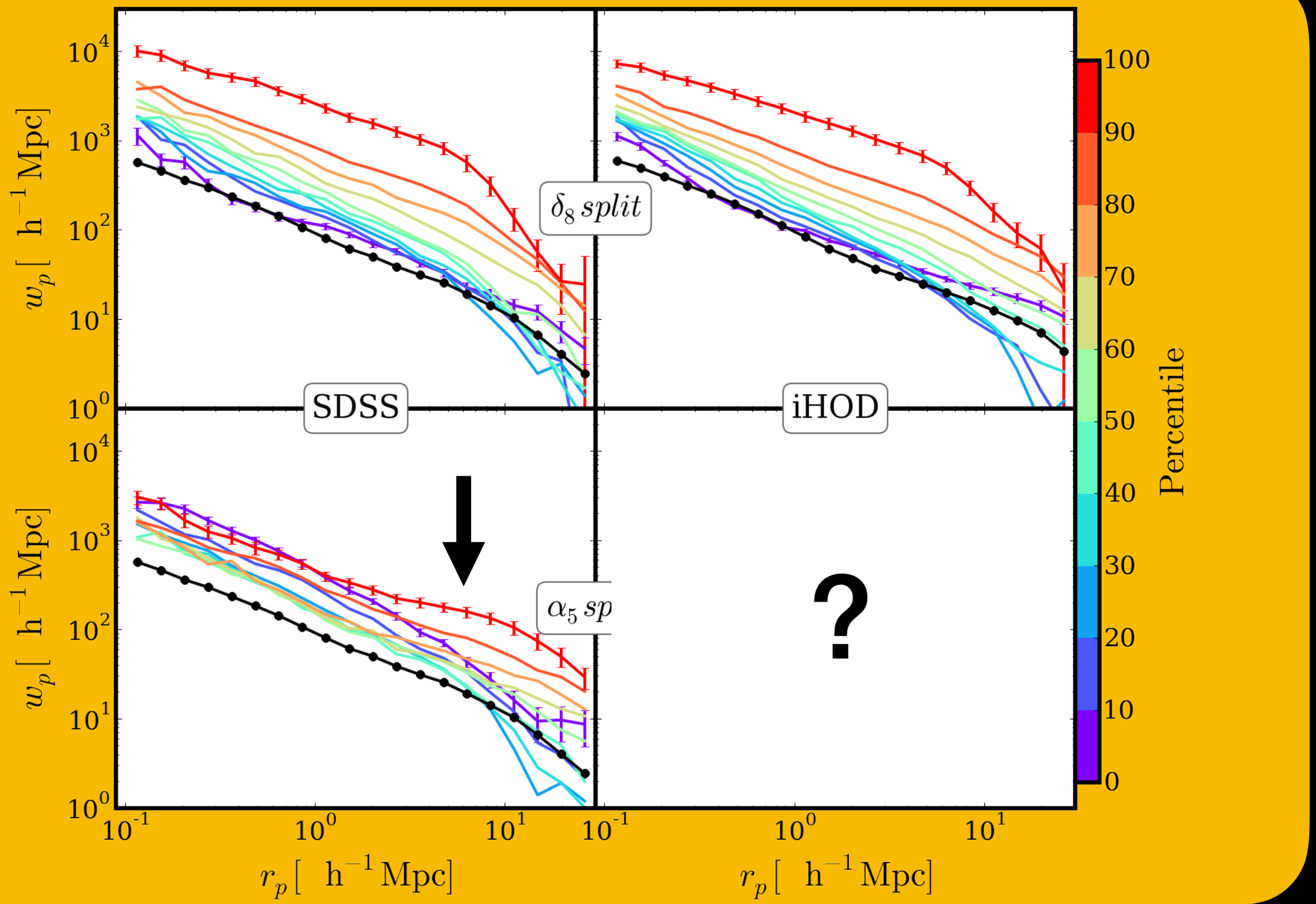
# Stellar Mass function



# Galaxy Quenching



# Projected Correlation function



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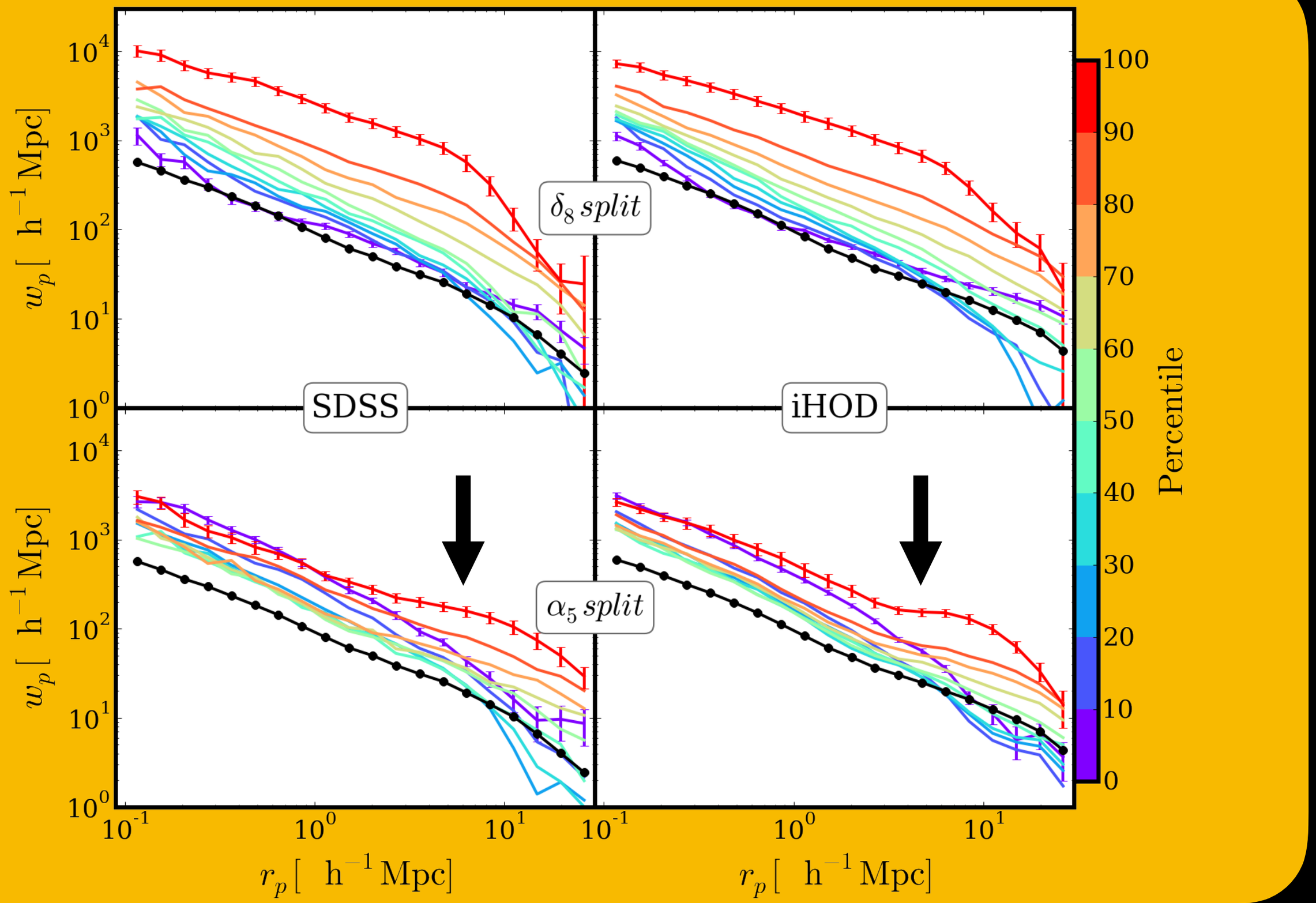
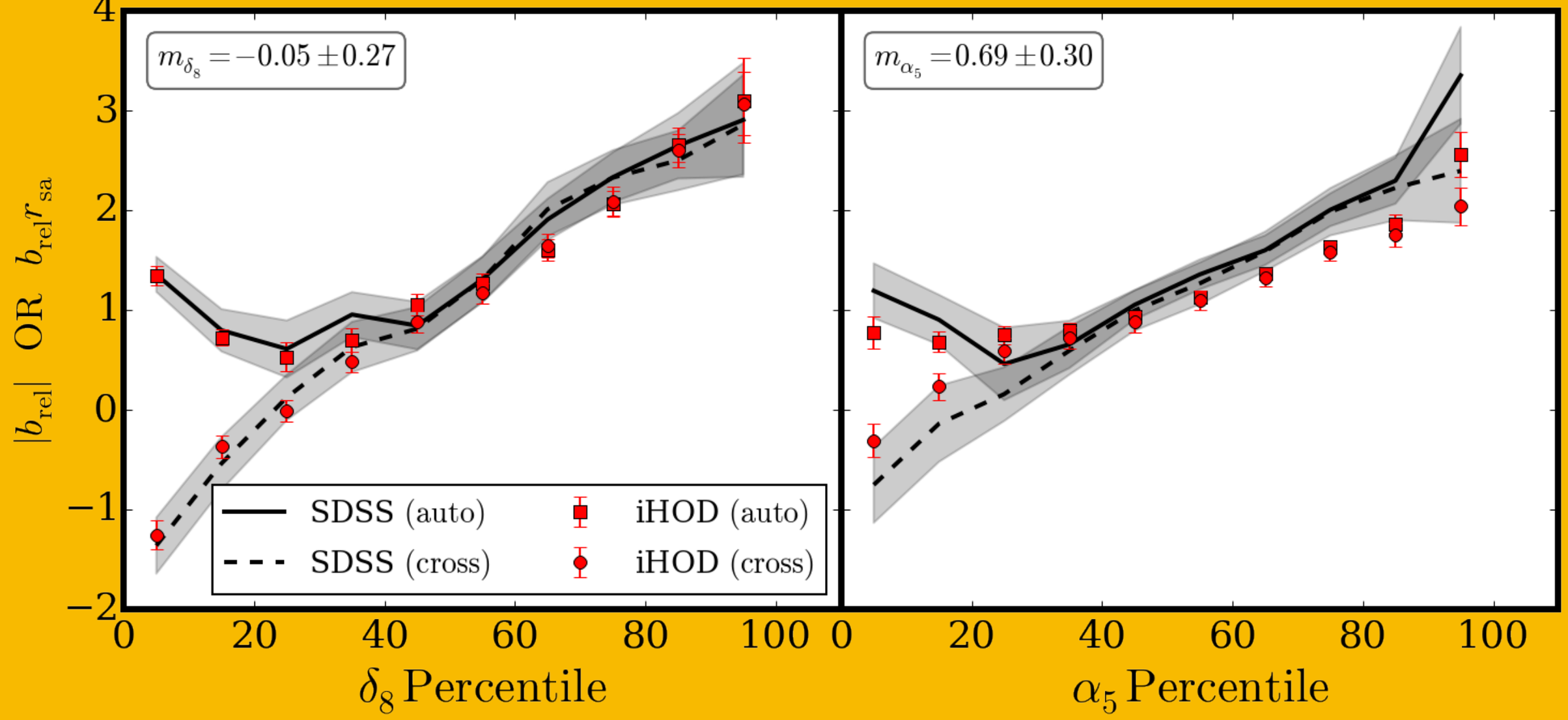
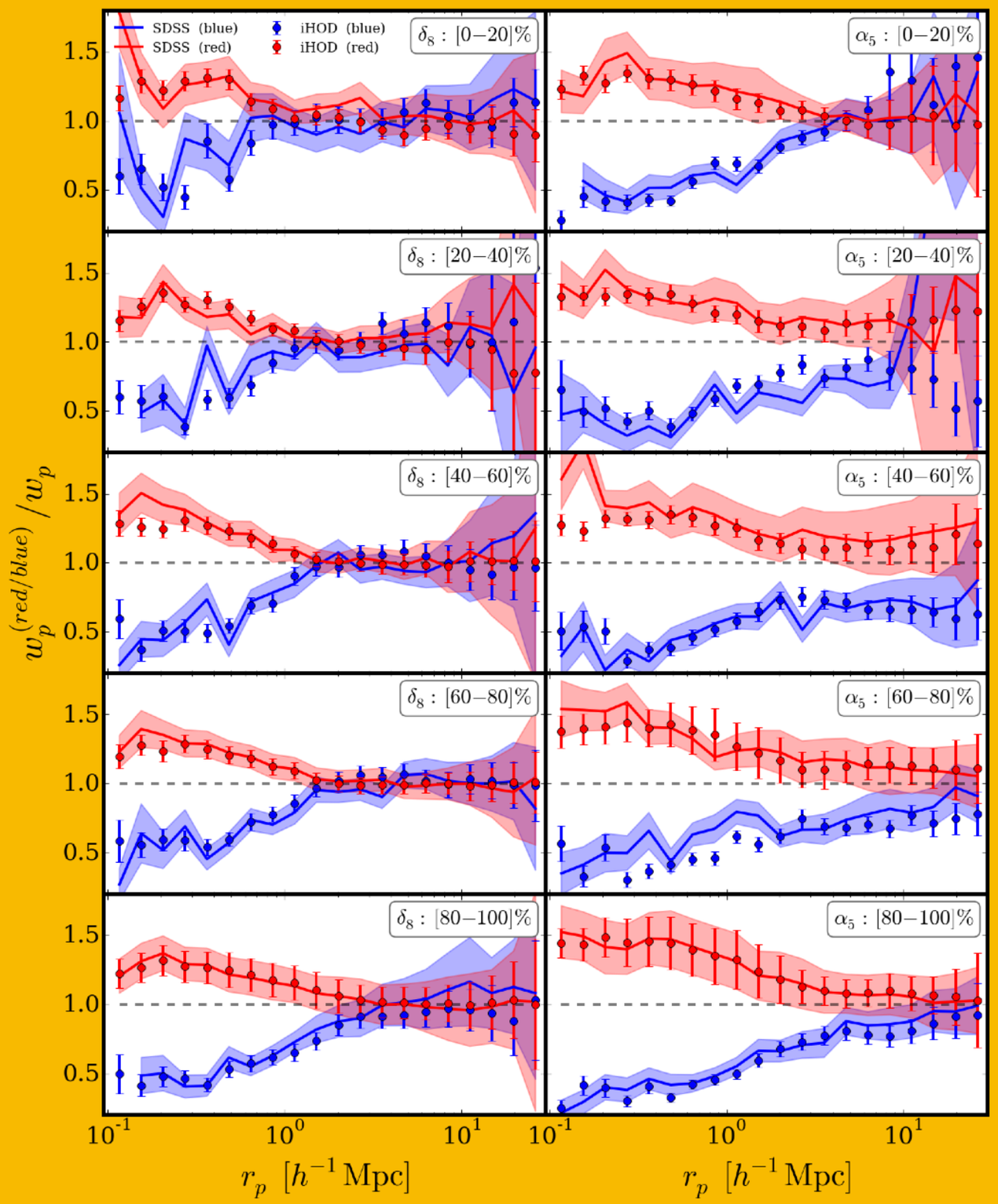


# Galaxies Bias

$$\delta_g = b\delta_m$$



# Cross-Correlation



# Summary

- **Over-Density is primary driver of halo formation.**
- **Impact of galaxy formation in different over density environment is not observed in current data.**
- **Tidal anisotropy is a secondary environment independent of over-density.**
- **Tidal anisotropy strongly influence halo formation.**
- **No significant signature of galaxy formation is detected in different tidal anisotropy environment.**