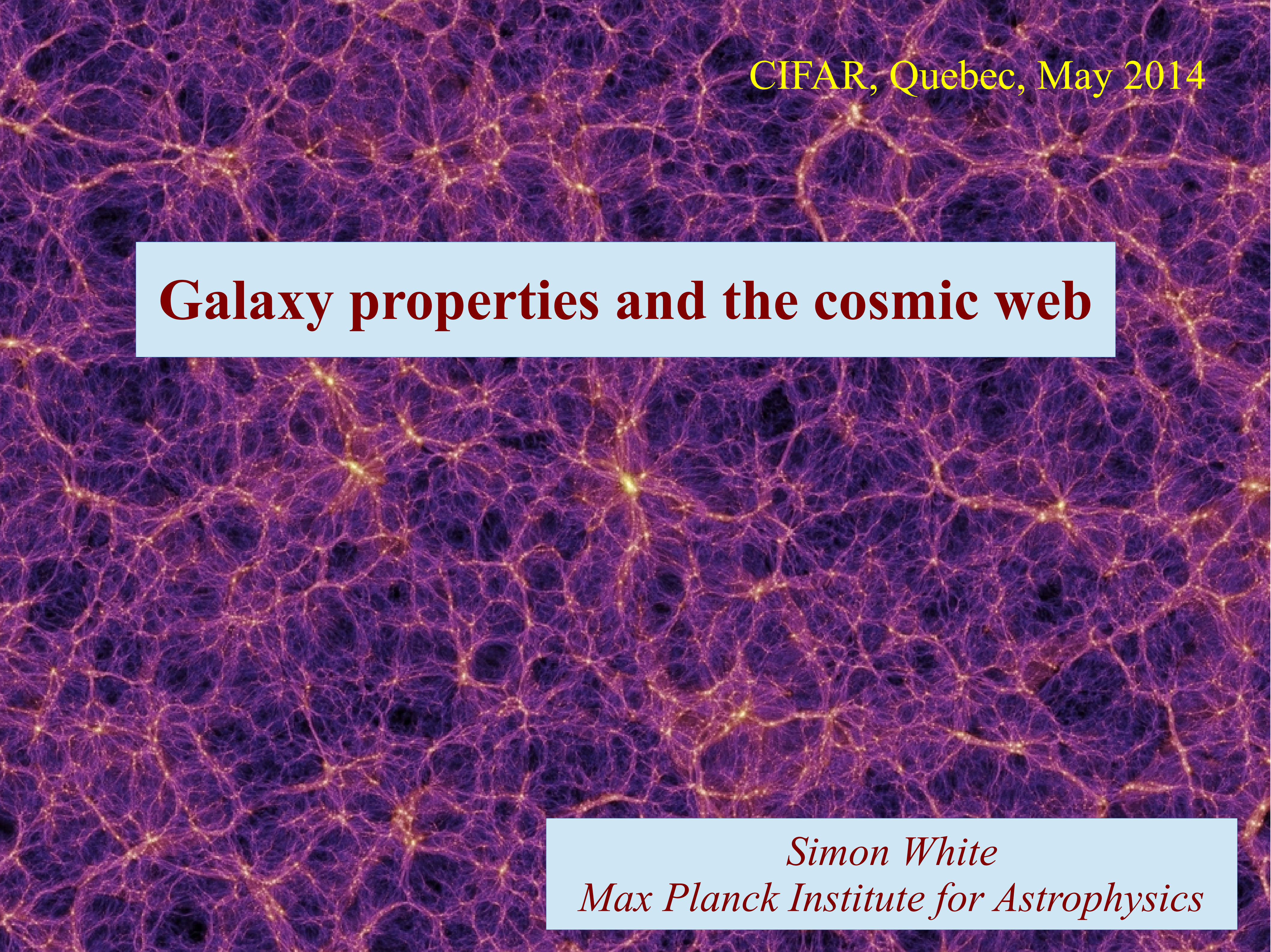


CIFAR, Quebec, May 2014

Galaxy properties and the cosmic web

Simon White
Max Planck Institute for Astrophysics

Galaxy properties are known to depend....

...on the *density* of their local environment

or alternatively

...on the *mass* of their "halo" and their location within it

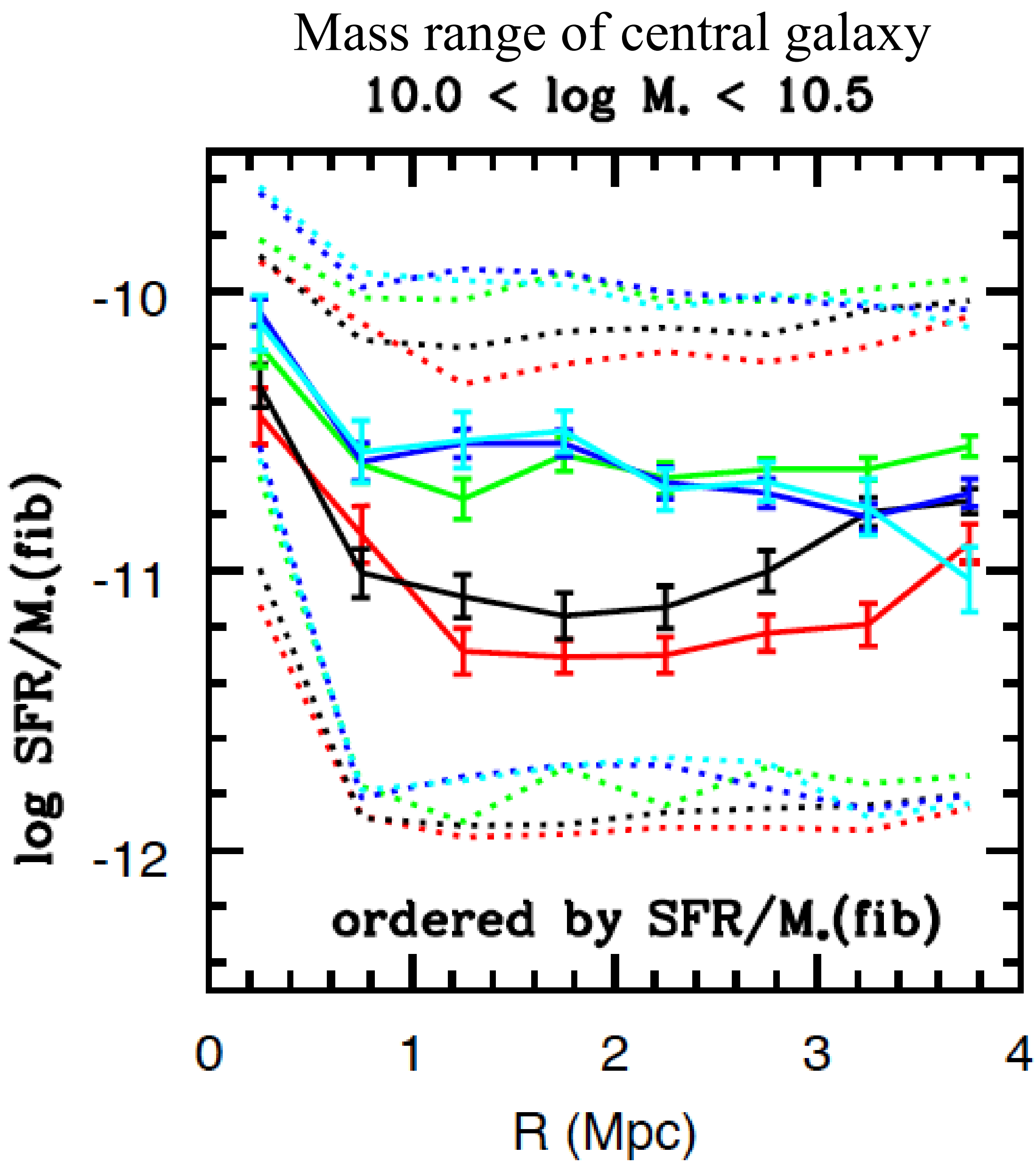
However....

* What is the relevant scale to estimate environment density?

* Are there dependences on other aspects of the cosmic web, for example, whether they live in a halo/filament/sheet/void?

* Do properties depend *only* on the mass/assembly history of their own halo, or are there larger scale dependences?

Kauffmann et al 2013



⟨sSFR⟩ of companions with log $M_* > 9.3$

Quartiles of sSFR of the central galaxy

75% to 100%

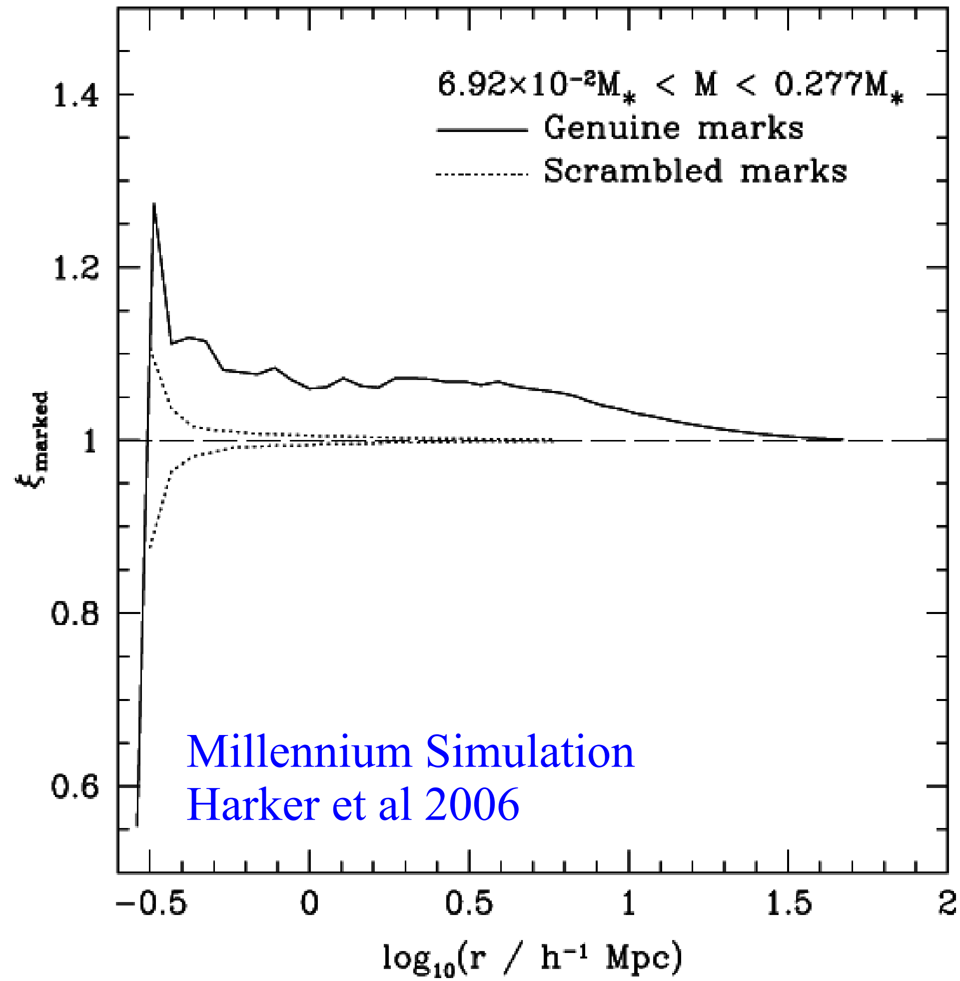
50% to 75%

25% to 50%

0% to 25%

Companions of central galaxies with a high sSFR tend to have a higher sSFR than those of centrals of the *same* mass with a low sSFR, even at distances greater than 10 R_{halo} -- "two-halo conformity"

Marked correlation function with scaled halo formation time as mark



Halos of a given mass ($\sim 10^{12} M_\odot$) which formed earlier than average tend to have companions which also formed earlier than average.

→ Formation histories of distinct halos are spatially correlated

The Morphology of the Cosmic Web...

...can be defined using a tidal tensor derived from the galaxy distribution

galaxy positions $\xrightarrow{\text{smoothing}}$ galaxy density field, $1 + \delta$

$\xrightarrow{\text{FFTs}}$ tidal tensor, $\partial^2\Phi/\partial x_i \partial x_j$

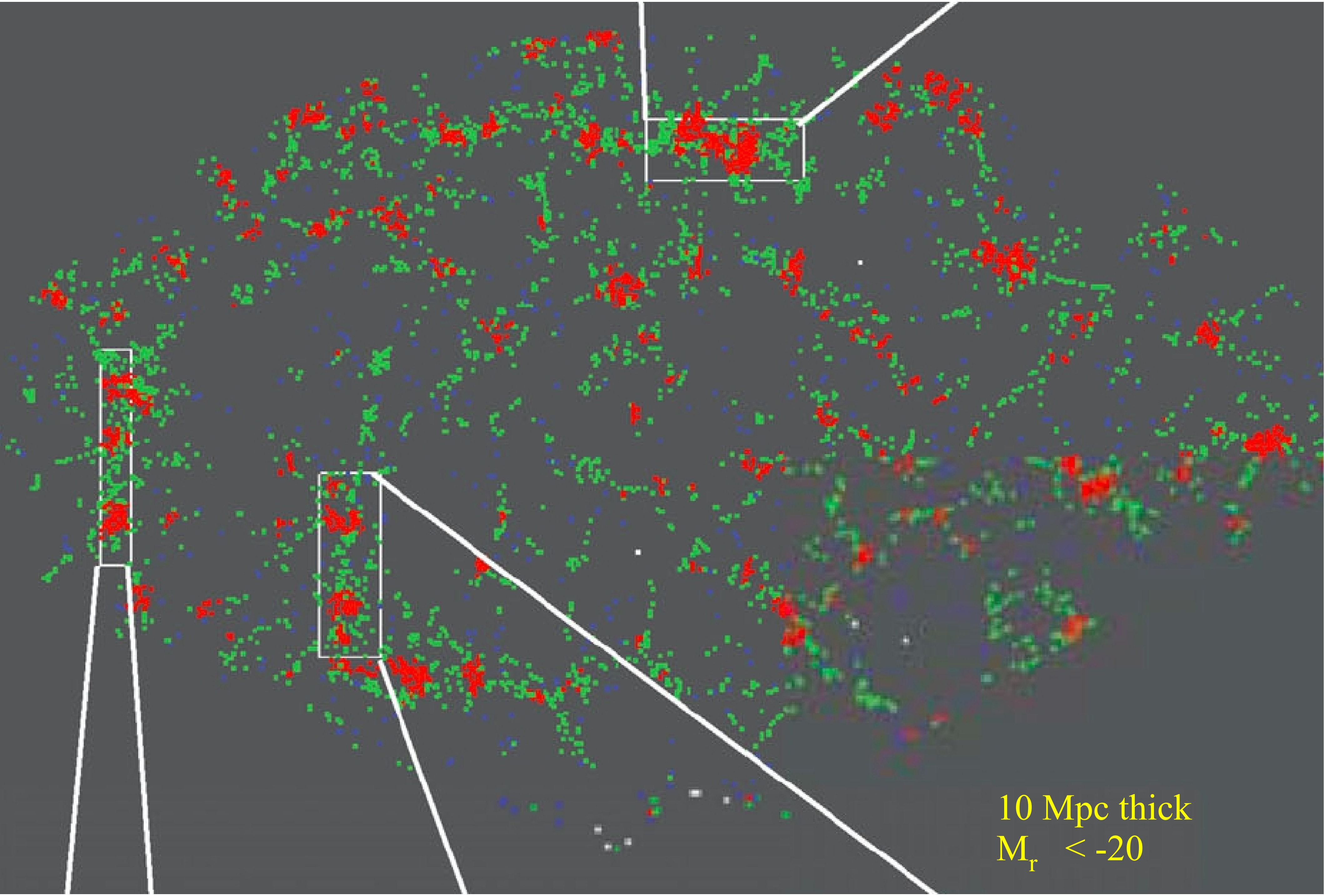
$\xrightarrow{\text{diagonalize}}$ E-values, $\lambda_1 > \lambda_2 > \lambda_3$

Use signs to define morphological elements:

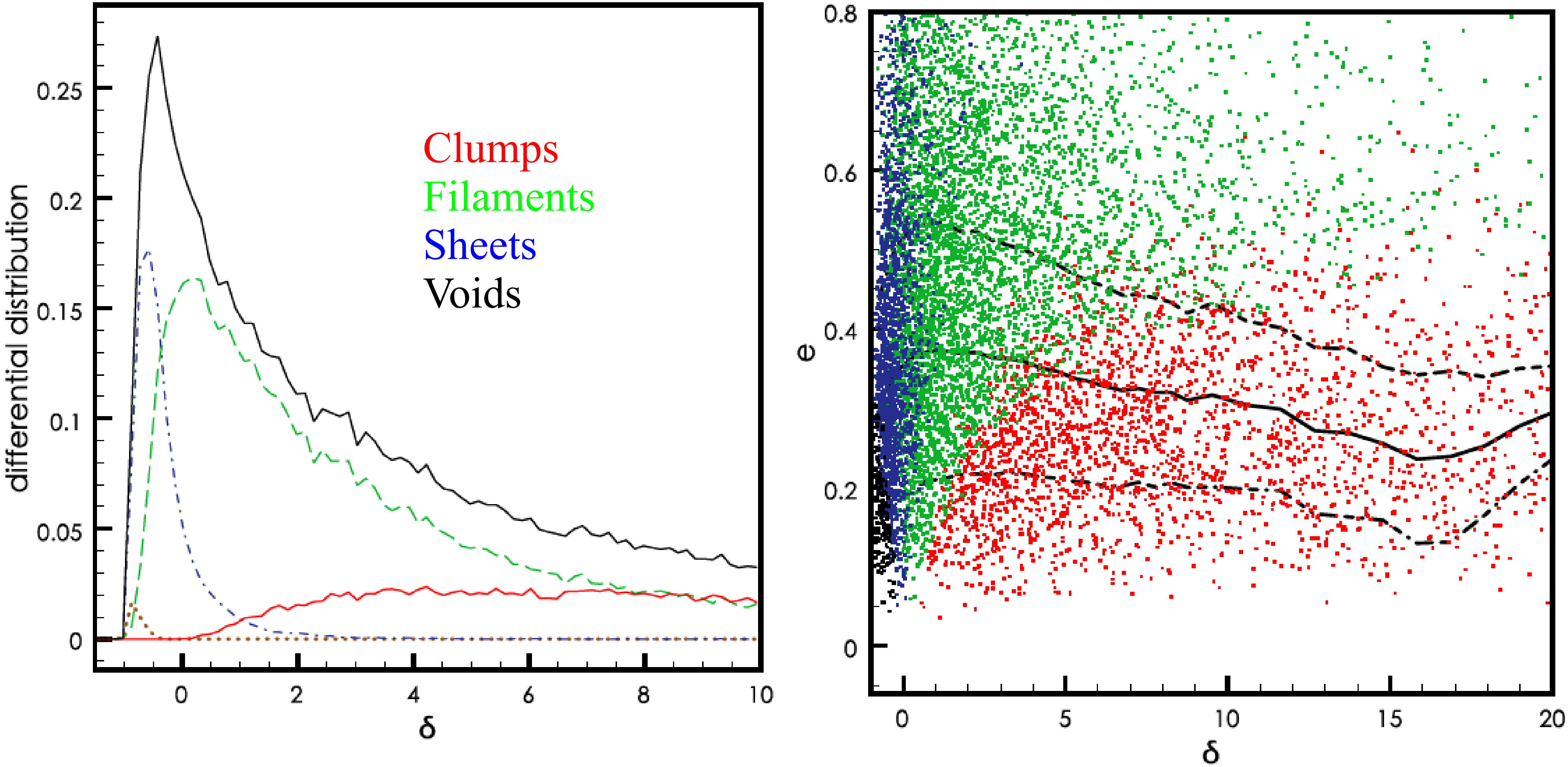
"clump"	$\lambda_3 > 0$
"filament"	$\lambda_2 > 0$, $\lambda_3 < 0$
"sheet"	$\lambda_1 > 0$, $\lambda_2 < 0$
"void"	$\lambda_1 < 0$

or use continuous variables:

$$1 + \delta = 1 + \lambda_1 + \lambda_2 + \lambda_3 \qquad e = \frac{\lambda_1 - \lambda_3}{3 + \delta}, \qquad p = \frac{\lambda_1 + \lambda_3 - 2\lambda_2}{3 + \delta}$$


10 Mpc thick
$M_r < -20$

SDSS/DR7 $M_r < -20 + 5 \log h$; $\sim 10^5$ galaxies Yan, Fan & White 2013



* The density distributions of e-value defined structures overlap strongly

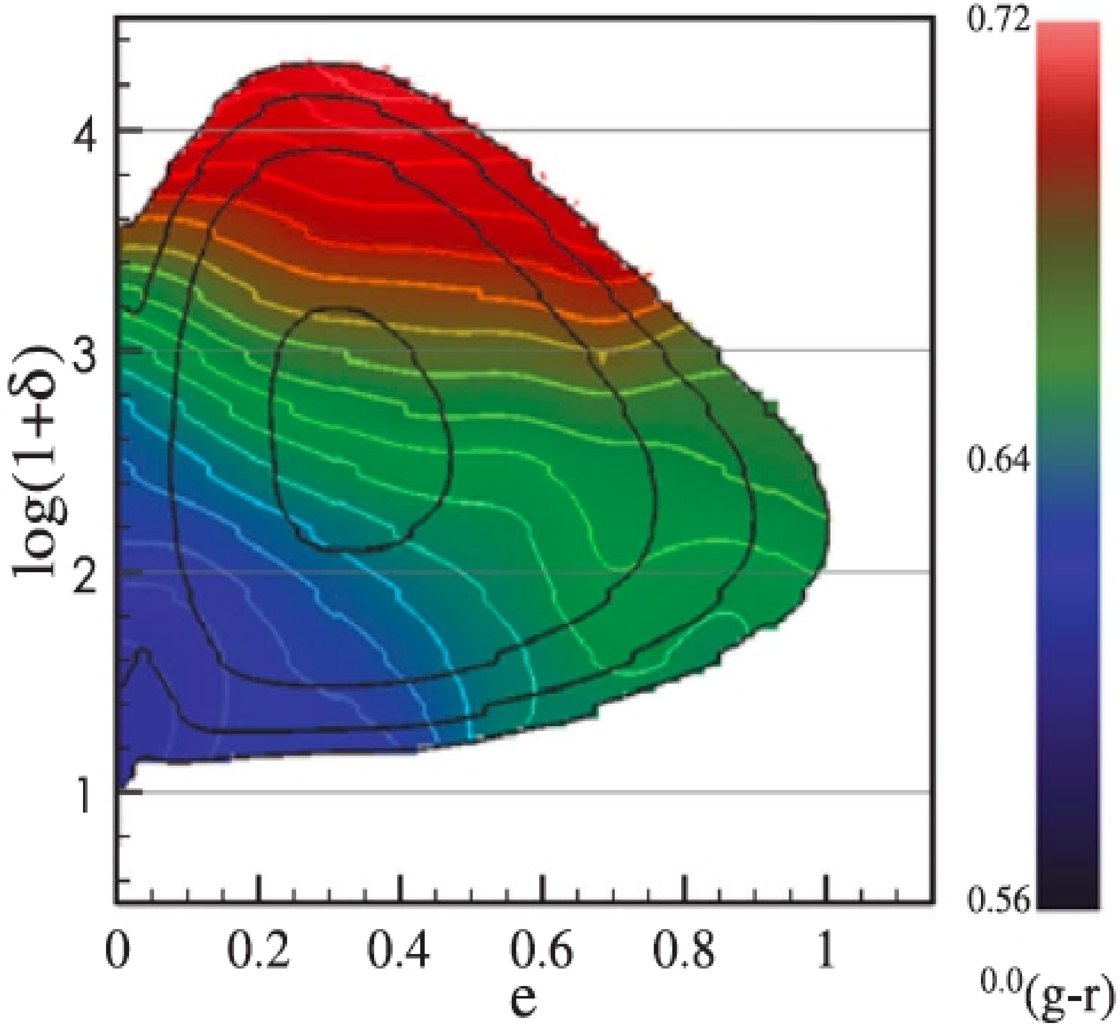
* Most galaxies lie in “clumps” and filaments

* Defining $e = \dfrac{\lambda_1 - \lambda_3}{3 + \delta}$ leads to a weak correlation of e with $1 + \delta$

Dependence of galaxy colour on 1 + δ and e

SDSS/DR7 $M_r <$ -20 + 5 log *h*

Yan, Fan & White 2013

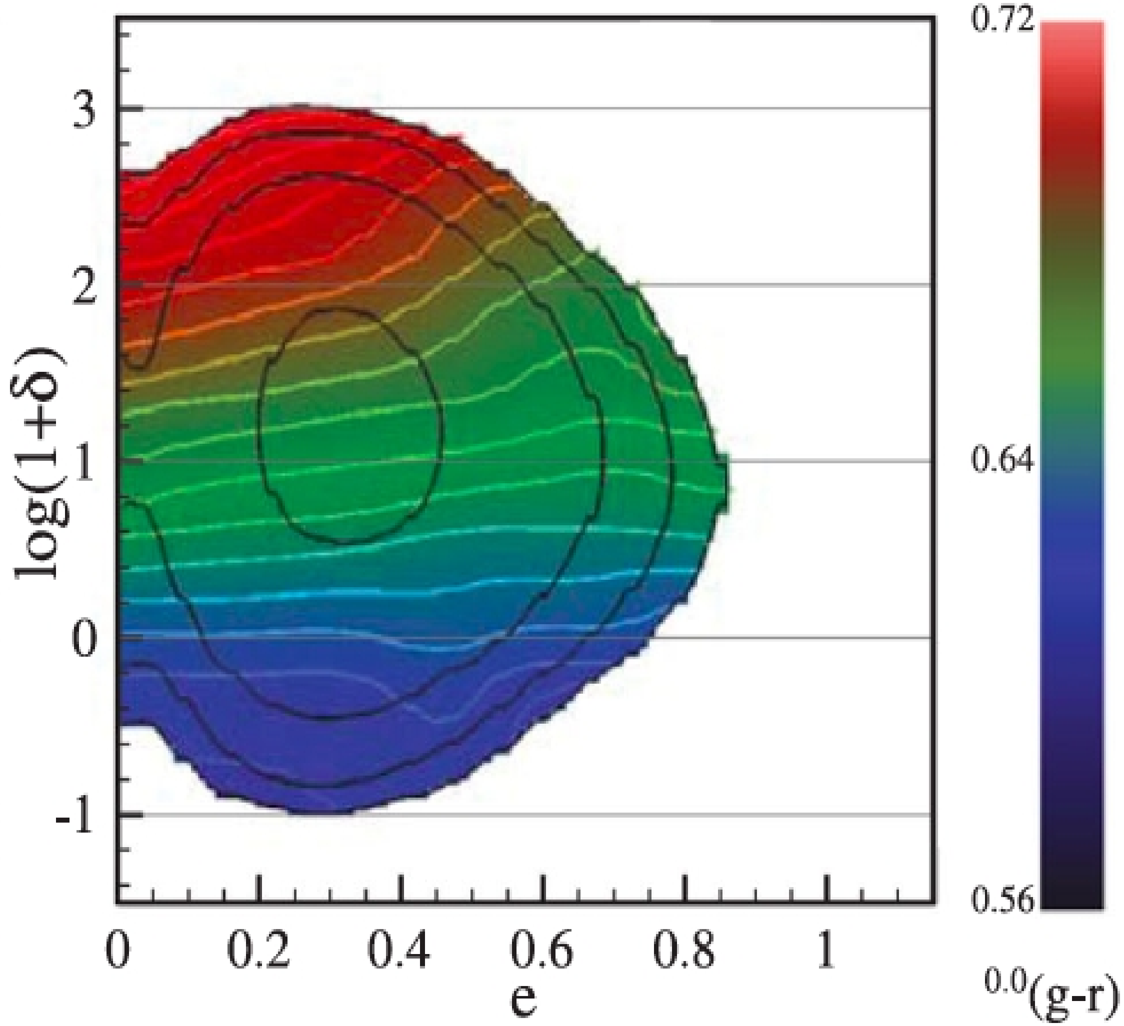


For R_{smooth} = 1 Mpc/*h*, galaxies get redder with increasing e at fixed 1 + δ

Dependence of galaxy colour on $1 + \delta$ and e

SDSS/DR7 $M_r < -20 + 5 \log h$

Yan, Fan & White 2013

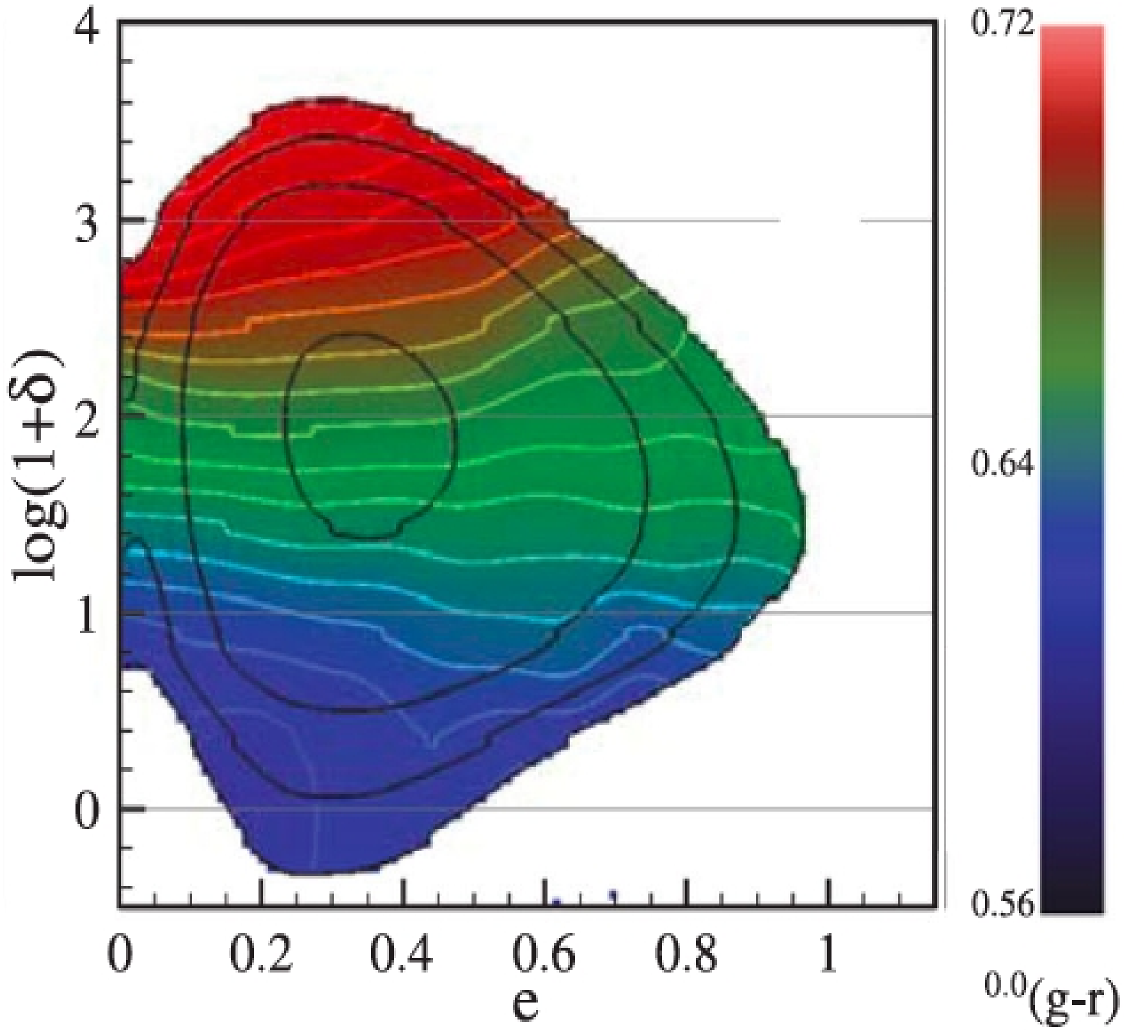


For $R_{smooth} = 3$ Mpc/h, galaxies get bluer with increasing e at fixed $1 + \delta$

Dependence of galaxy colour on $1 + \delta$ and e

SDSS/DR7 $M_r < -20 + 5 \log h$

Yan, Fan & White 2013

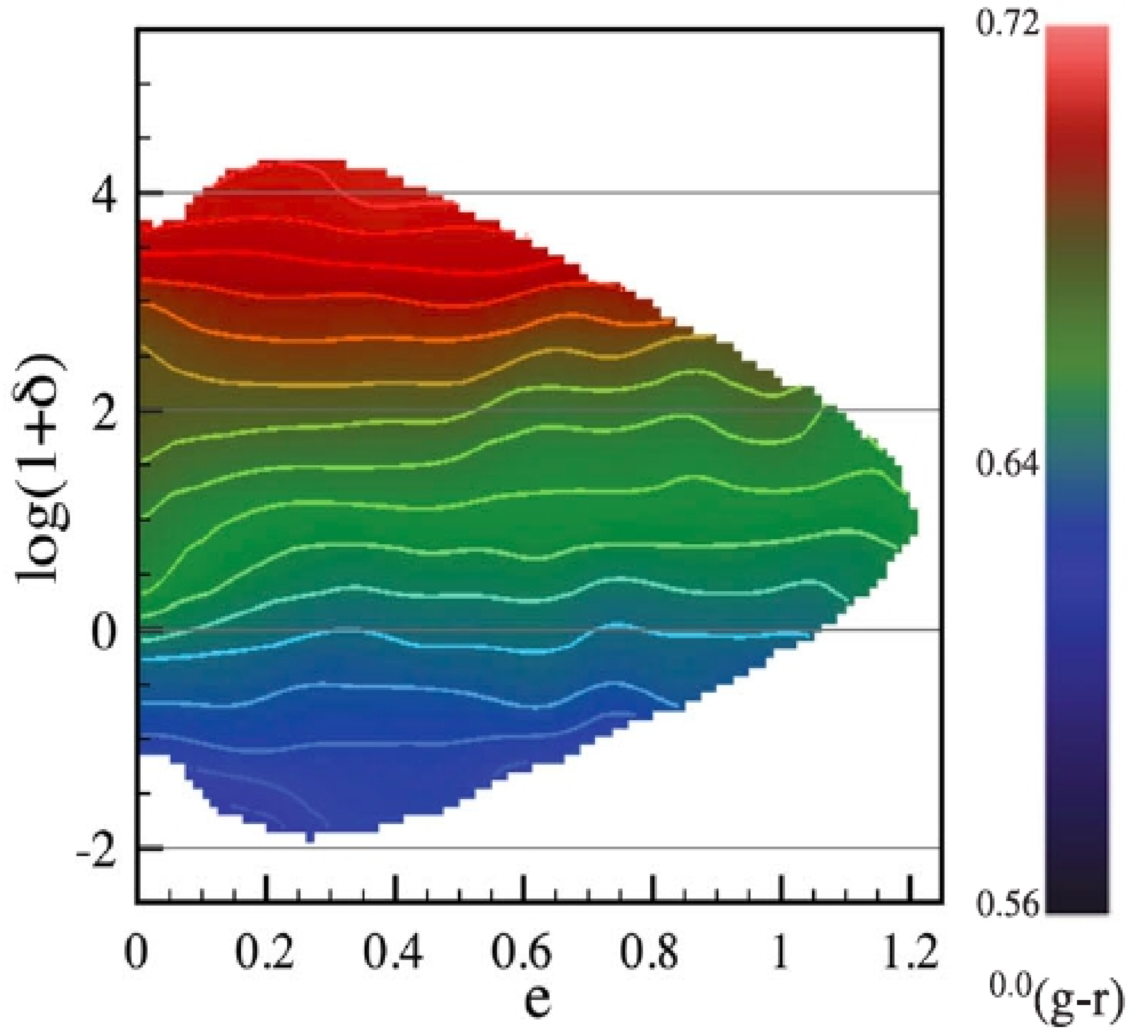


For R_{smooth} = 2 Mpc/h, galaxies get bluer with increasing e at large $1 + \delta$,

galaxies get redder with increasing e at small $1 + \delta$

Dependence of galaxy colour on $1 + \delta$ and e

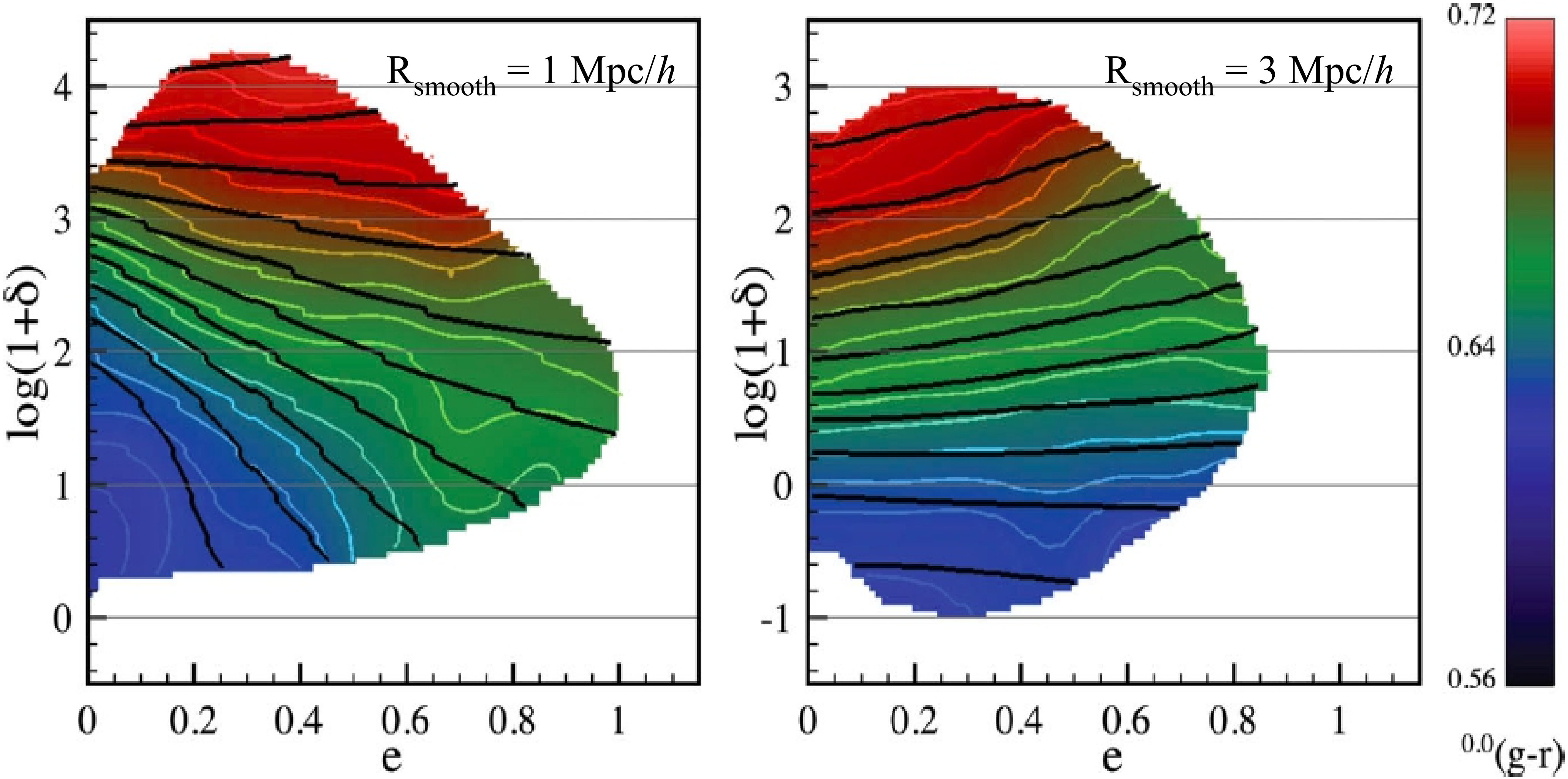
SDSS/DR7 $M_r < -20 + 5 \log h$ Yan, Fan & White 2013



For adaptive smoothing based on distance to 3rd nearest neighbour, galaxy colour is *independent* of e at fixed $1 + \delta$. This smoothing also *maximizes* the correlation between colour and $1 + \delta$

Dependence of galaxy colour on $1 + \delta$ and e

SDSS/DR7 $M_r < -20 + 5 \log h$ Yan, Fan & White 2013

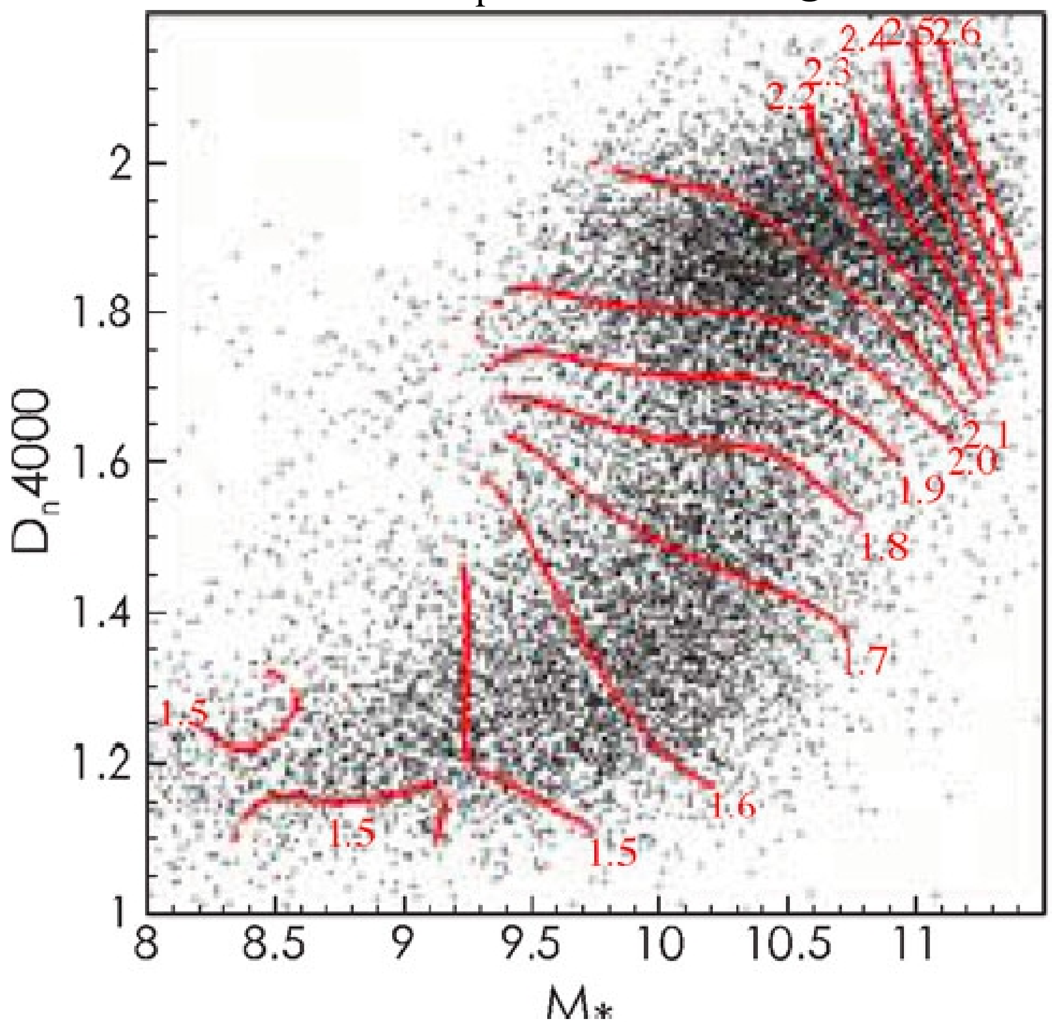


For fixed smoothing, the contours of constant colour are the same shape as the contours of mean optimal adaptively smoothed density $1 + \delta_0$ (black lines).

→ trends seen previously are due to sub-optimal smoothing

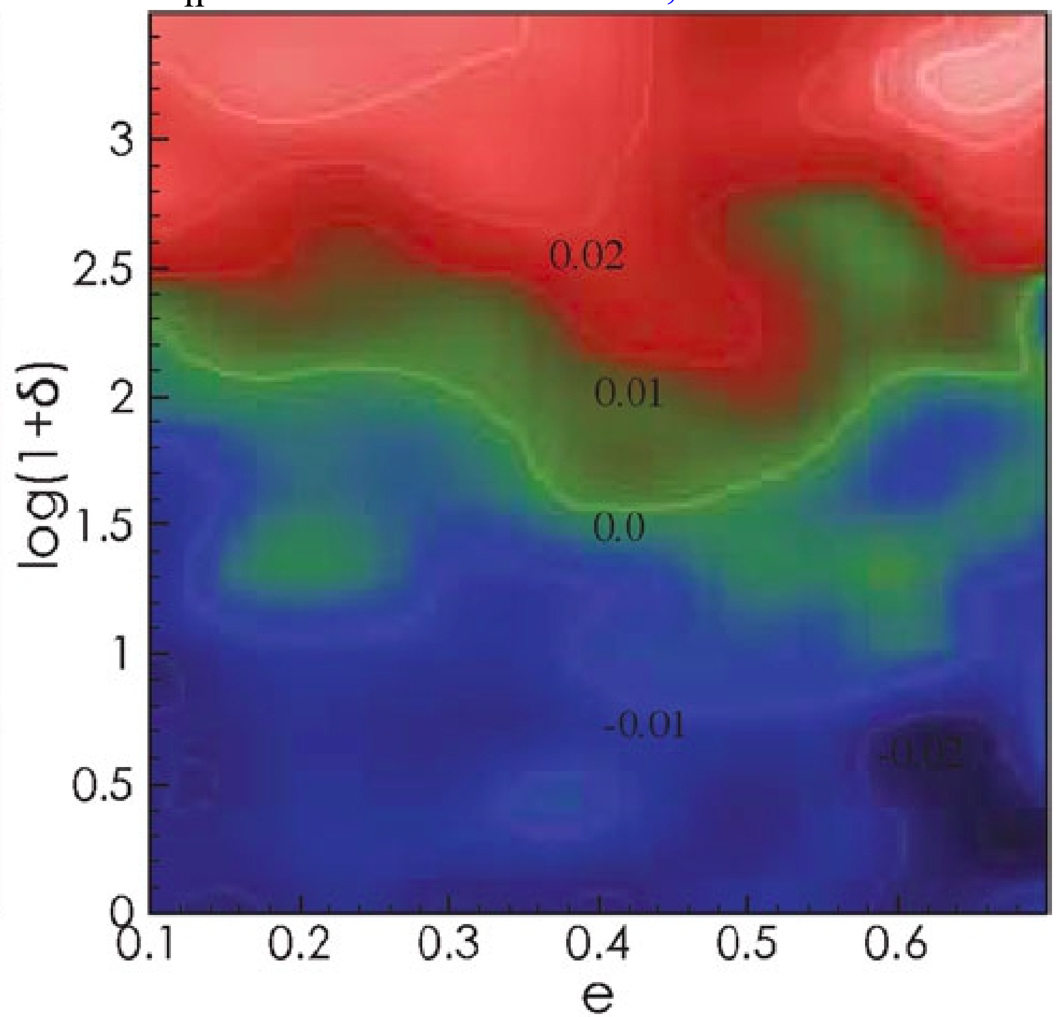
Environment dependences in the $M_* - D_n4000$ plane

SDSS/DR7 $M_r < -20 + 5 \log h$



D_n4000 excess

Yan, Fan & White 2013

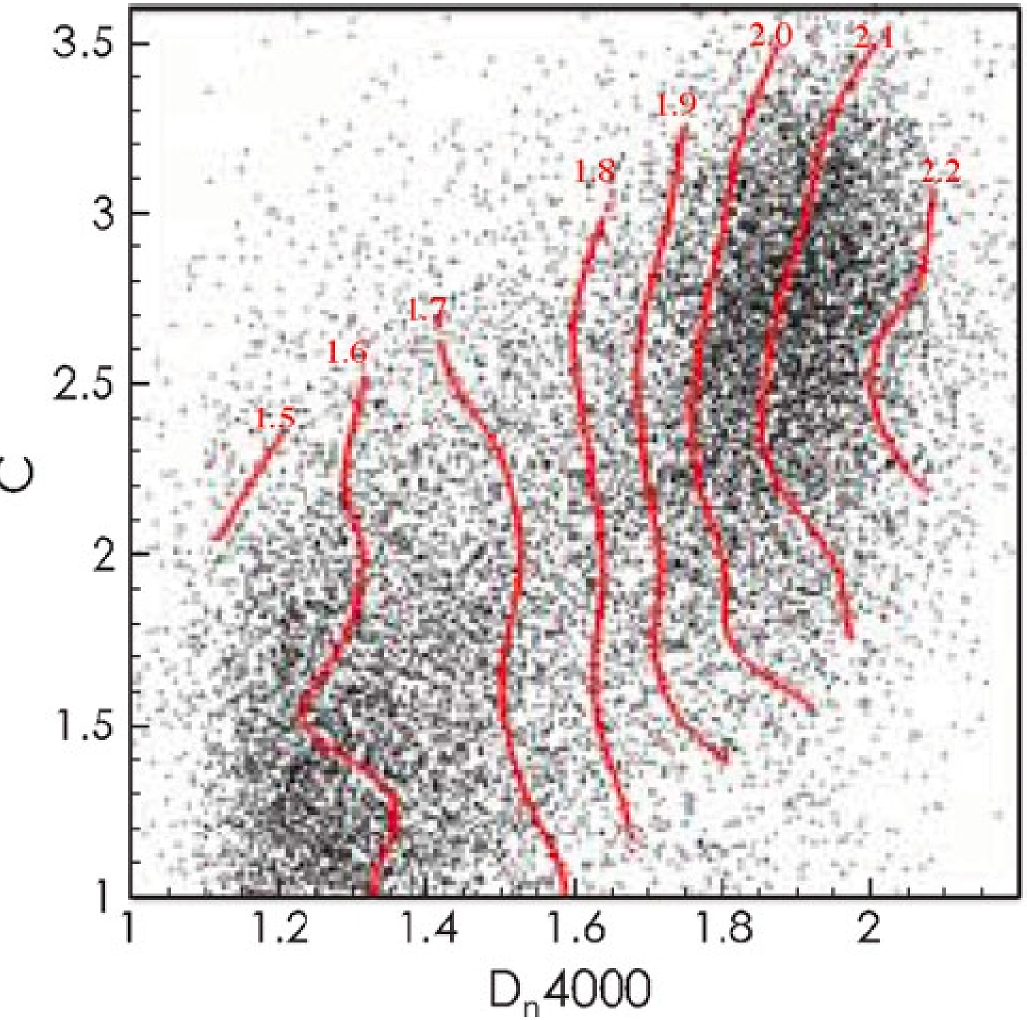


* Typical $1 + \delta_0$ values for galaxies depend on *both* M_* and D_n4000

* At fixed M_* and $1 + \delta_0$ there is no additional D_n4000 dependence on e

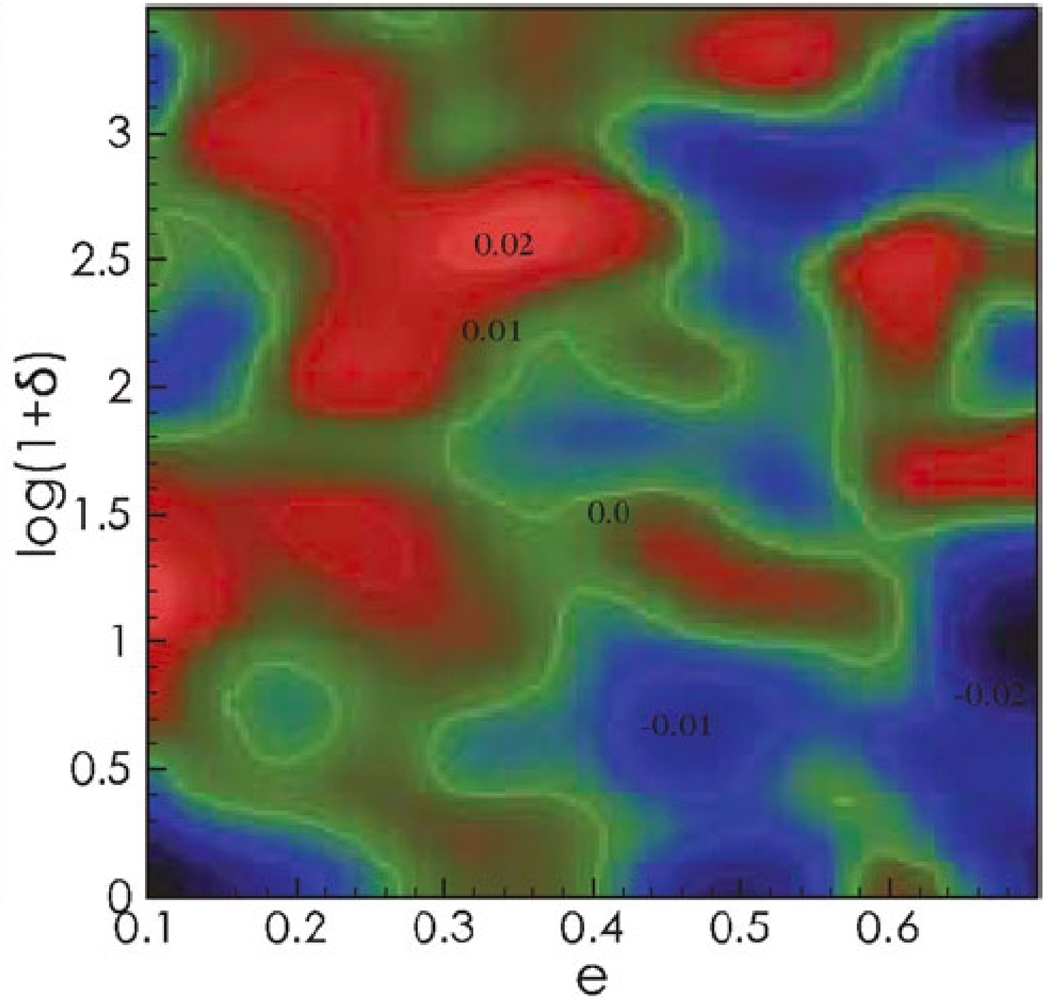
Environment dependences in the D_n4000 - C plane

SDSS/DR7 $M_r < -20 + 5 \log h$



C excess

Yan, Fan & White 2013



* Typical $1 + \delta_0$ values for galaxies depend on M_* but not on concentration C

* Concentration $C = R_{90}/R_{50}$ at fixed M_* is independent of both $1 + \delta_0$ and e

Conclusions?

- "Galactic conformity" extends beyond individual halos

  The central galaxies of neighboring halos tend to have similar sSFR even at R ~ 3Mpc and after controlling for M_*

  → large-scale processes modulate galaxy formation?

- The assembly histories of neighboring halos are correlated

  The growth of halos depends on larger scale environment even at fixed final halo mass

  → a possible origin for conformity effects?

- For optimal smoothing, galaxy properties vary with local density only

  There is no additional dependence on the <u>morphology</u> of structure

- For other smoothings, the density dependence is weakened and (non-physical) dependences on morphology are induced

- SFR/gas content depend strongly on density, structure only weakly