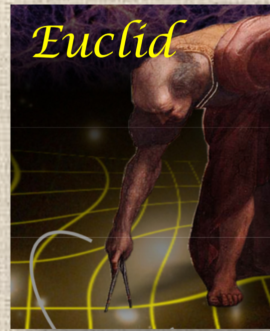

Redshift-space distortions with EUCLID: a key probe of the growth history of structure

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on behalf of the EUCLID team
(EUCLID-NIS science team and EUCLID Cosmology Working Group)

Cosmic acceleration: a story with two sides…

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^4} T_{\mu\nu} + \Lambda g_{\mu\nu}$$

Modify gravity theory [e.g. ***R*** → ***f(R)***]

Add dark energy

"…the Force be with you"

So, measuring the equation of state *w(z)* is not the end of the story…

Cosmic acceleration can also be explained by modifying the theory of gravity [as e.g. in *f(R)* theories, Capozziello et al. 2005, or in multi-dimensional "braneworld" models, Dvali et al. (DGP) 2000].

→ How to distinguish between these two options, observationally?

Growth of linear density fluctuations $\delta = \delta\rho/\rho$ in the expanding Universe (in GR):

$$\boxed{\ddot{\delta} + 2H(t)\dot{\delta} = 4\pi G\langle\rho\rangle\delta}$$

which has a growing solution:

$$\boxed{\delta^{+}(\bar{x},t) = \hat{\delta}(\bar{x})D(t)}$$

from which we define a *growth rate*

$$\boxed{f \equiv \frac{d\ln D}{d\ln a}}$$

→ The growth equation (and thus the growth rate) depends not only on the expansion history *H(t)* (and thus on *w*) but also on the gravitation theory (e.g. Lue et al. 2004)

Understanding cosmic acceleration: the quest for two functions

$$w(z)$$

$$f(z)$$

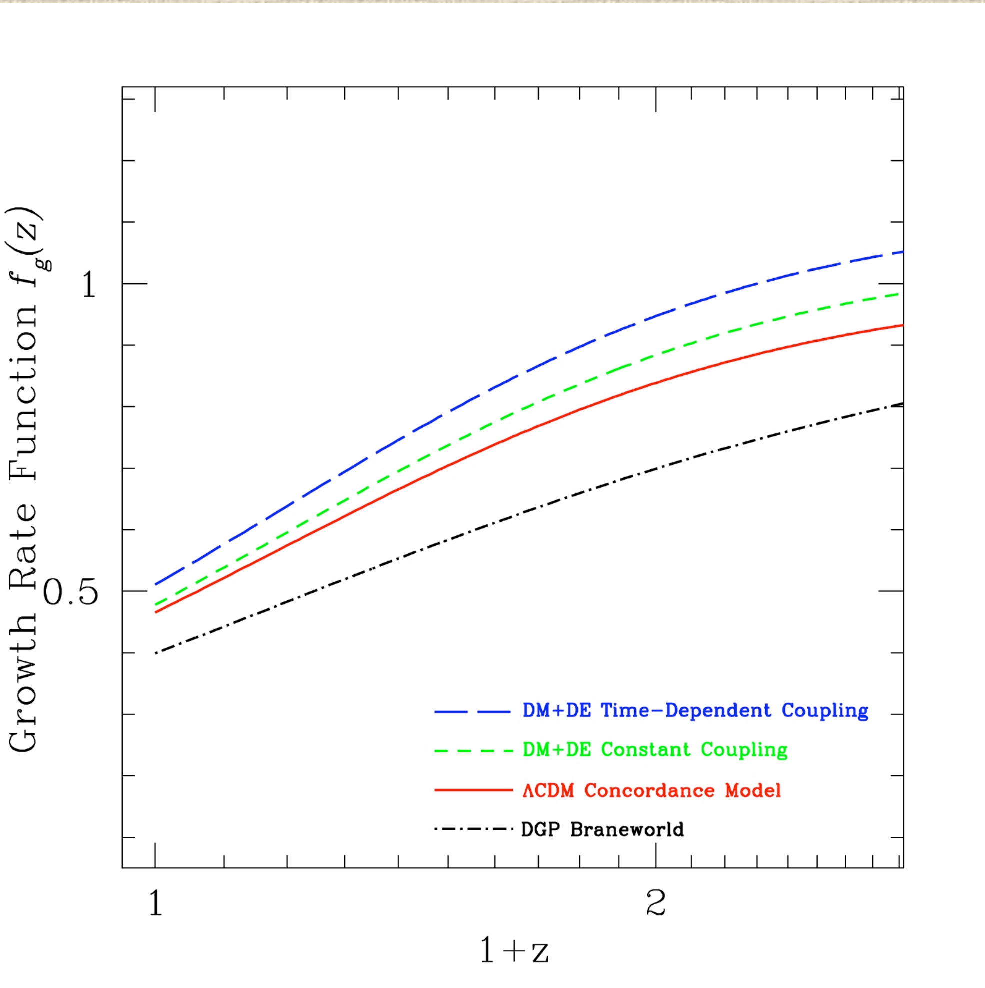
Measurements of the growth rate evolution *f(z)* break the degeneracy between models with same effective expansion history [thus same *w(z)*], but completely different physics (however, see Kunz & Sapone 2007)

For a wide variety of models

$$f(z)=[\Omega_m(z)]^\gamma$$

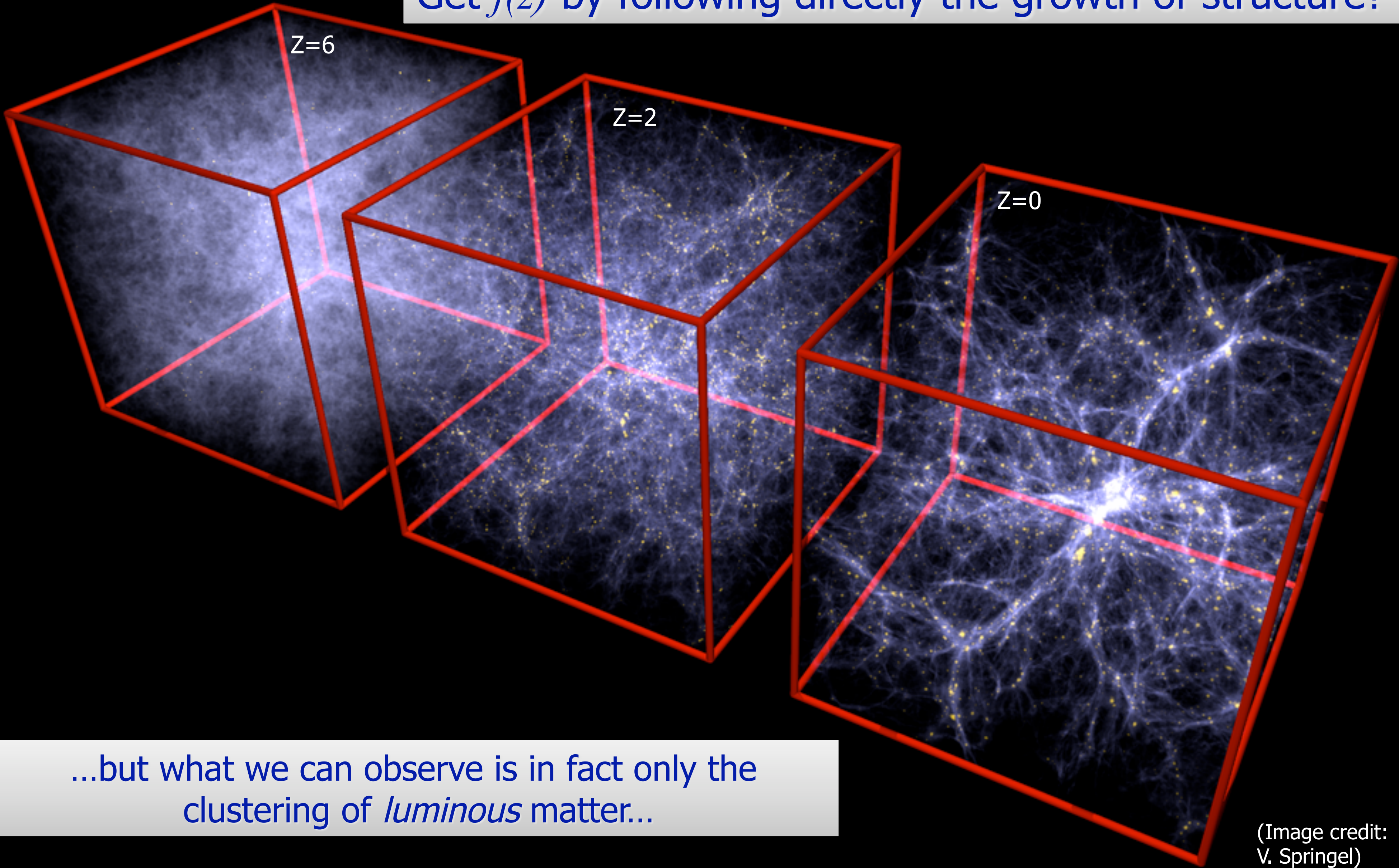
(Wang & Steinhardt 1998, Amendola et al. 2005, Linder 2005)

e.g.
γ=0.55 for standard Λ
γ=0.68 for DGP braneworld



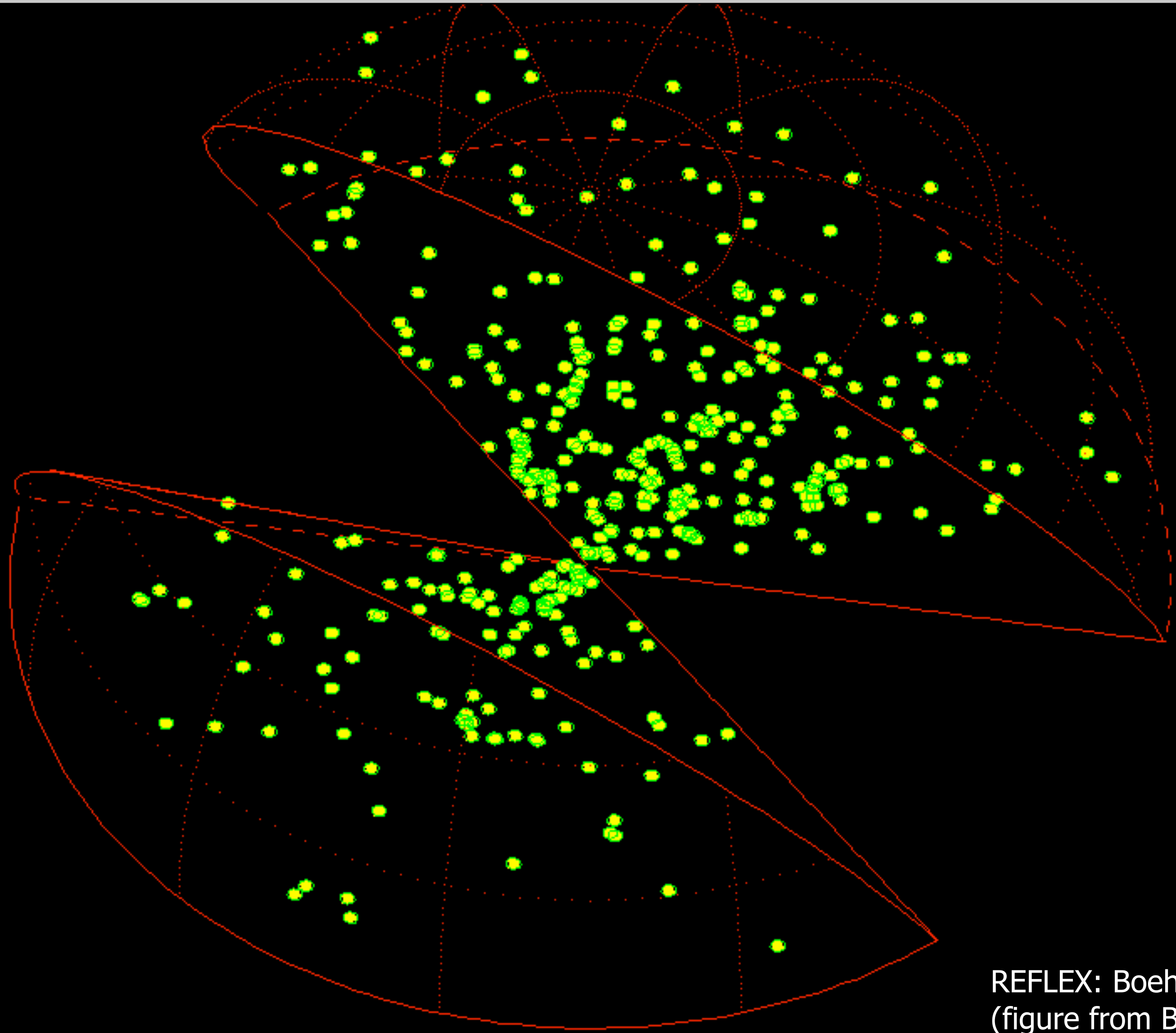
How do we measure *f(z)*?

Get $f(z)$ by following directly the growth of structure?



…but what we can observe is in fact only the clustering of *luminous* matter…

Or we can count the number density of X-ray clusters…

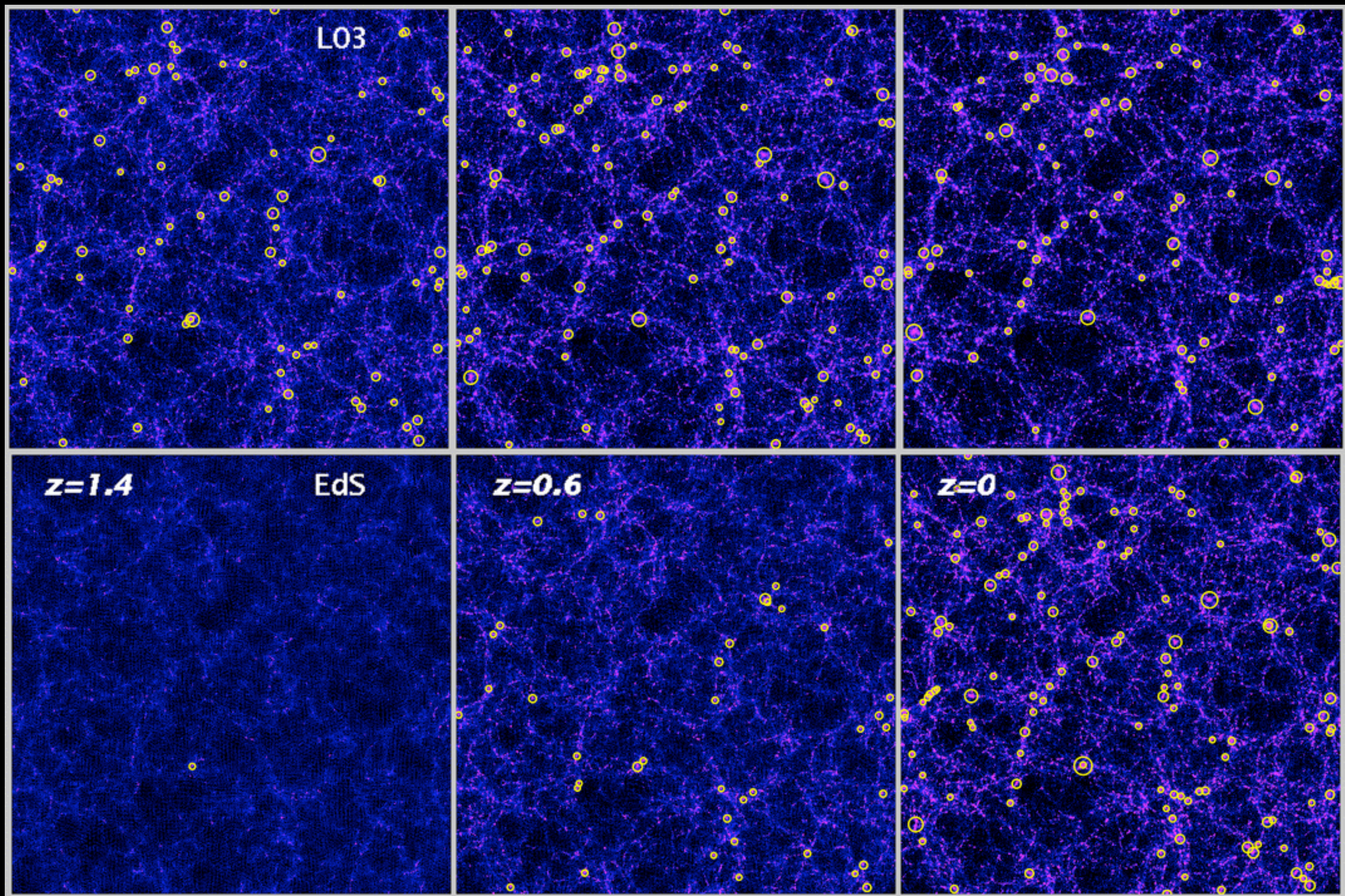


REFLEX: Boehringer et al. 2004
(figure from Borgani & Guzzo 2001)

…and how it evolves with redshifts: probing a combination of the growth rate f(z) and the expansion rate H(z)

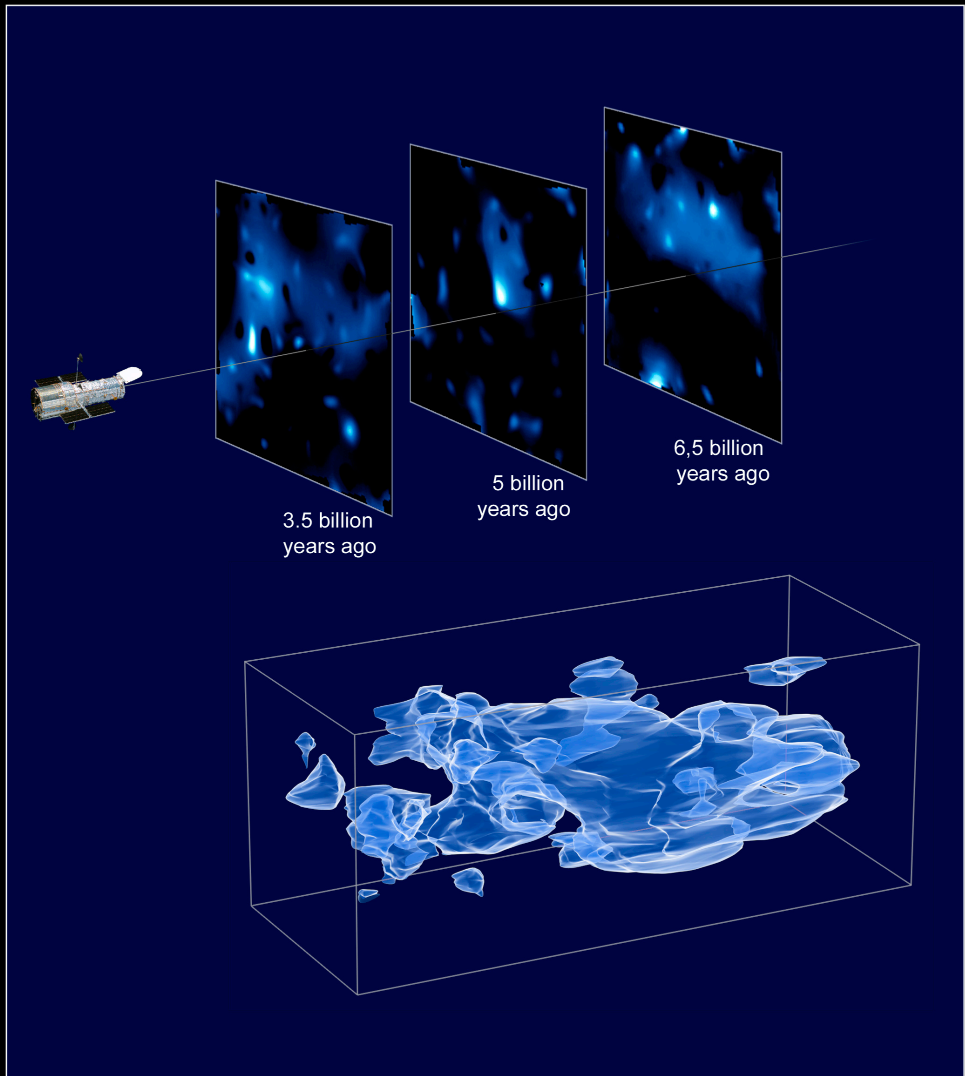
Lambda model

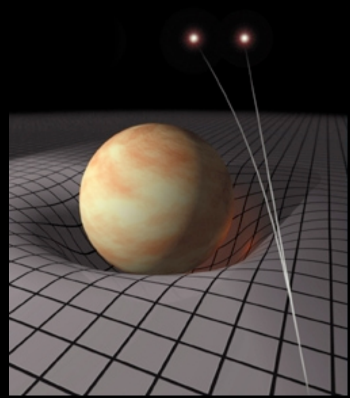
Einstein-DeSitter model



Borgani & Guzzo 2001

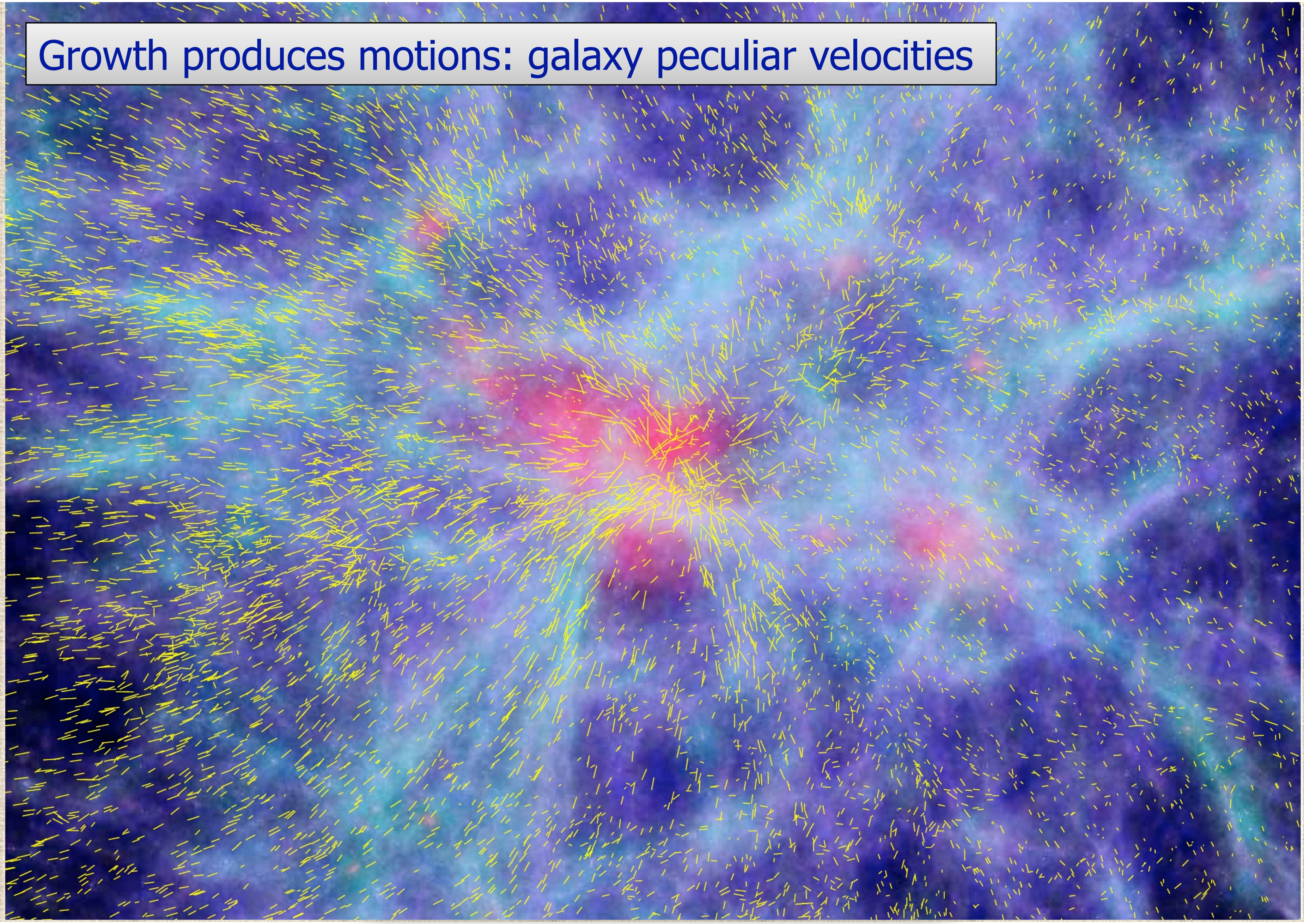
…or use weak gravitational lensing "tomography"





COSMOS: Massey et al. 2007

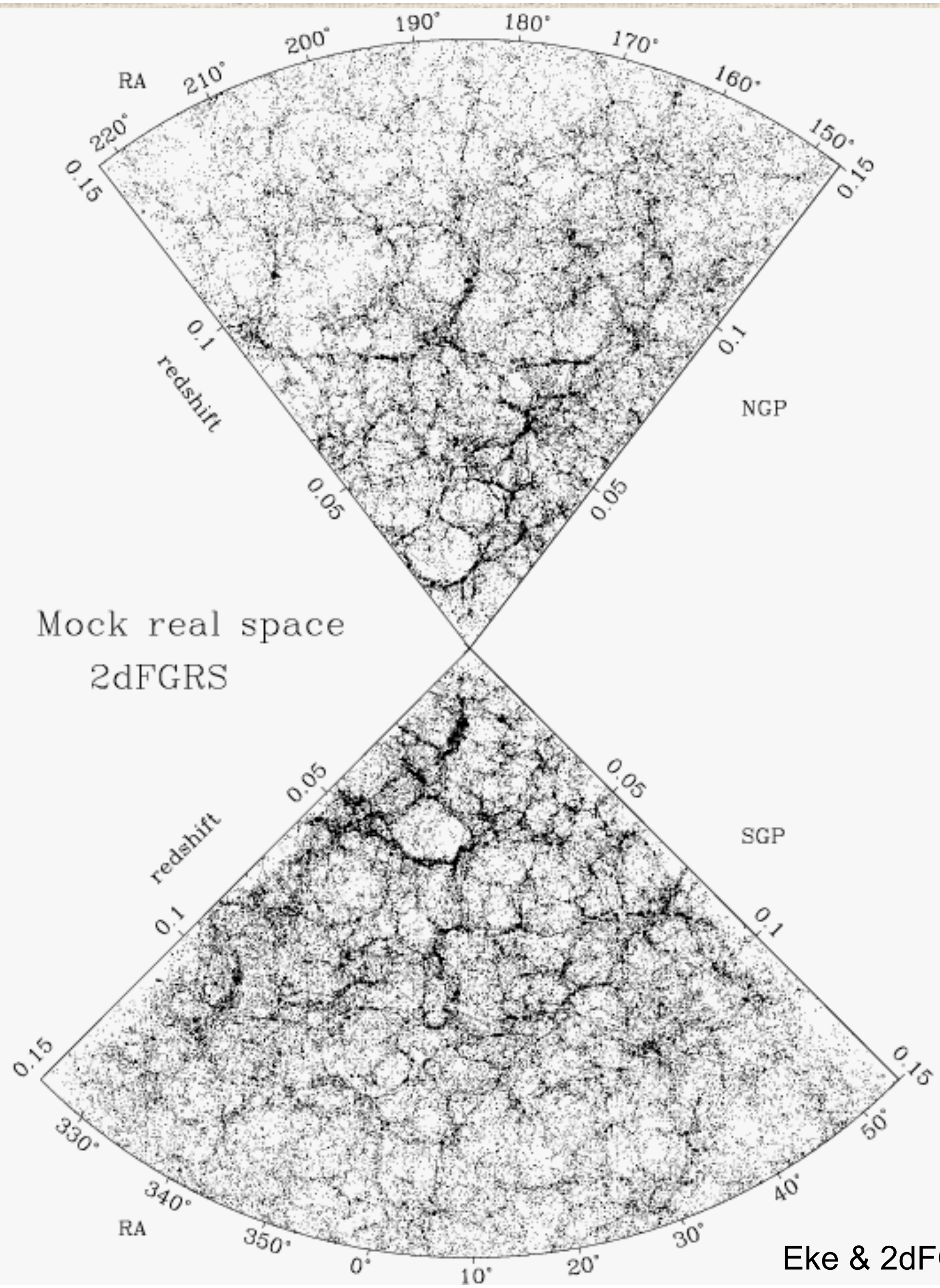
Growth produces motions: galaxy peculiar velocities



Peculiar velocities manifest themselves in galaxy redshift surveys as *redshift-space distortions*

real space

(Kaiser 1987)

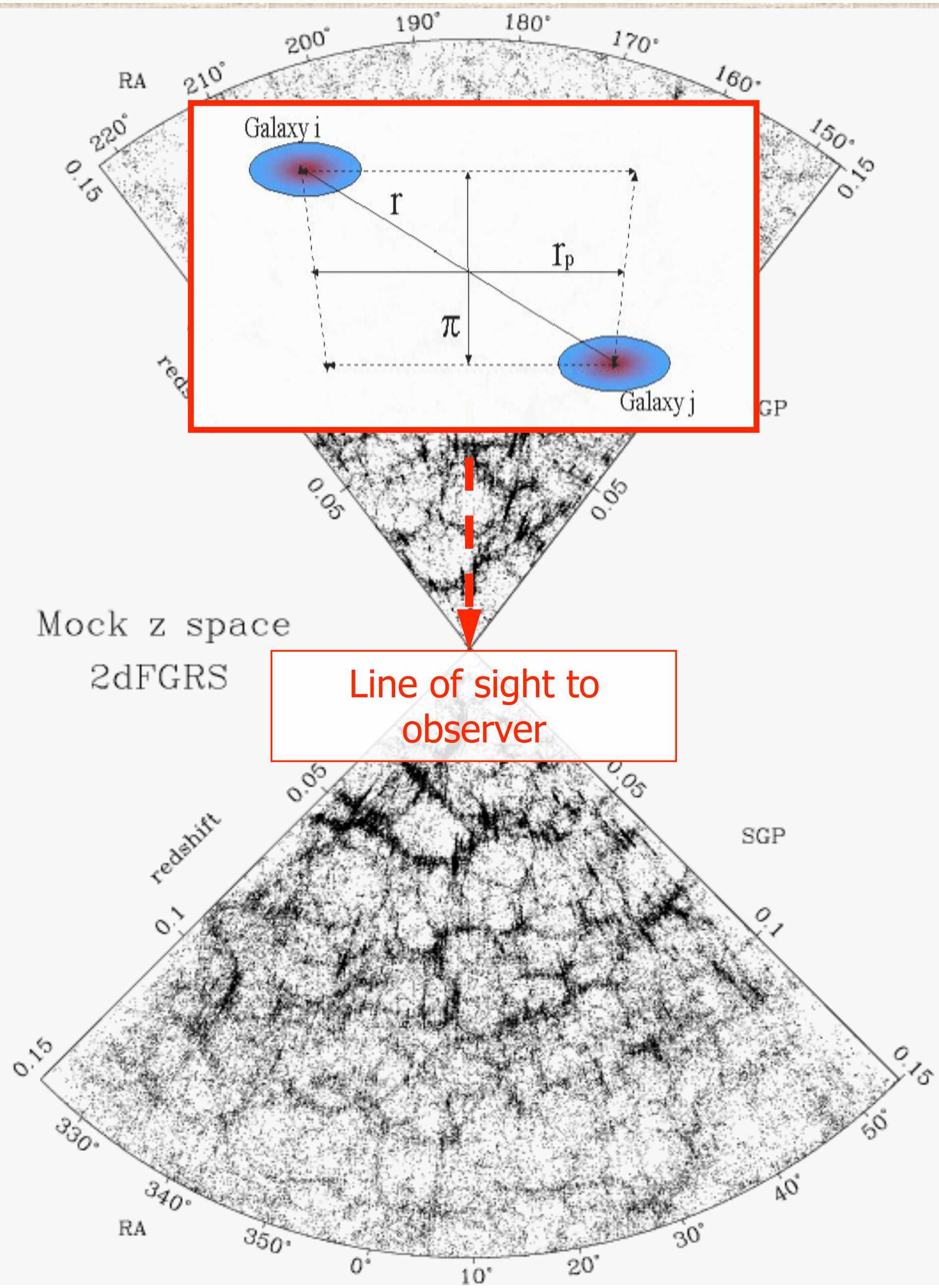


Eke & 2dFGRS 2003

Peculiar velocities manifest themselves in galaxy redshift surveys as *redshift-space distortions*

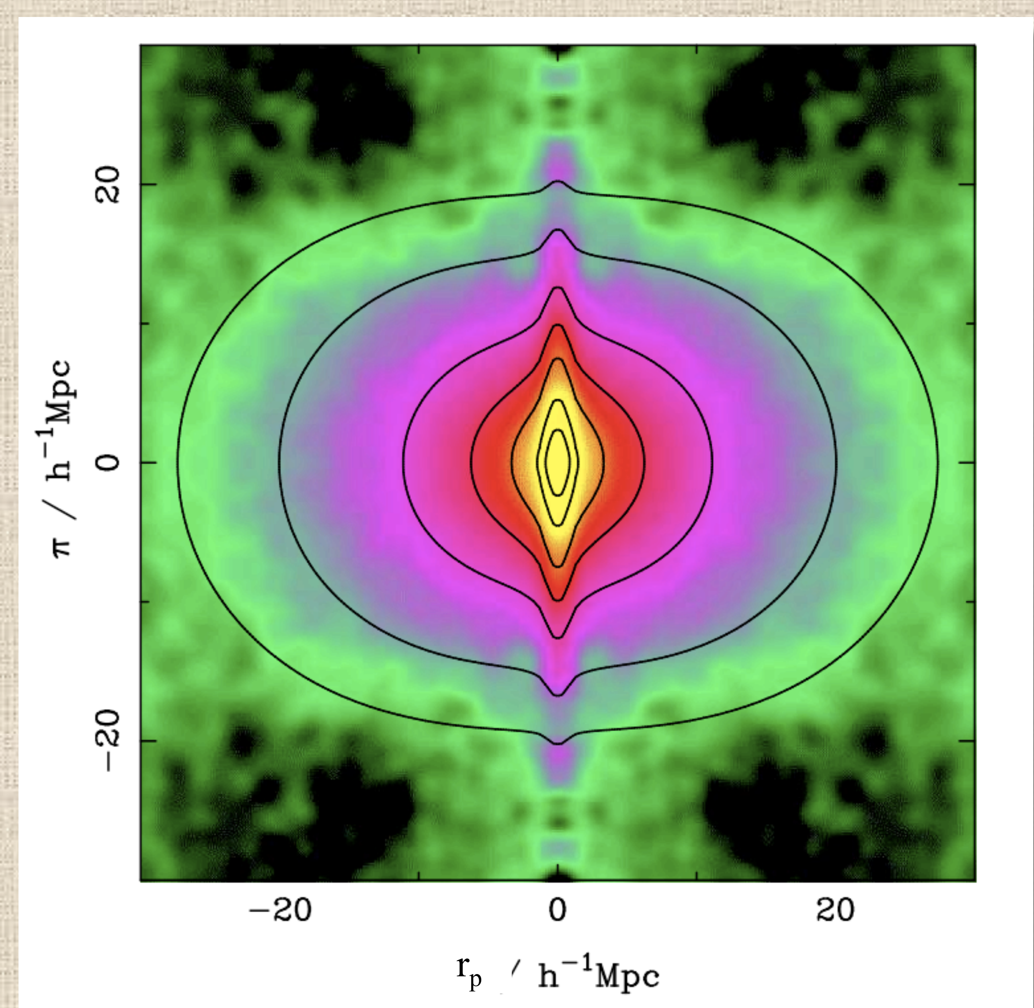
redshift space

(Kaiser 1987)



Redshift-space galaxy-galaxy correlation function $\xi(r_p,\pi)$

2dFGRS, z~0.1

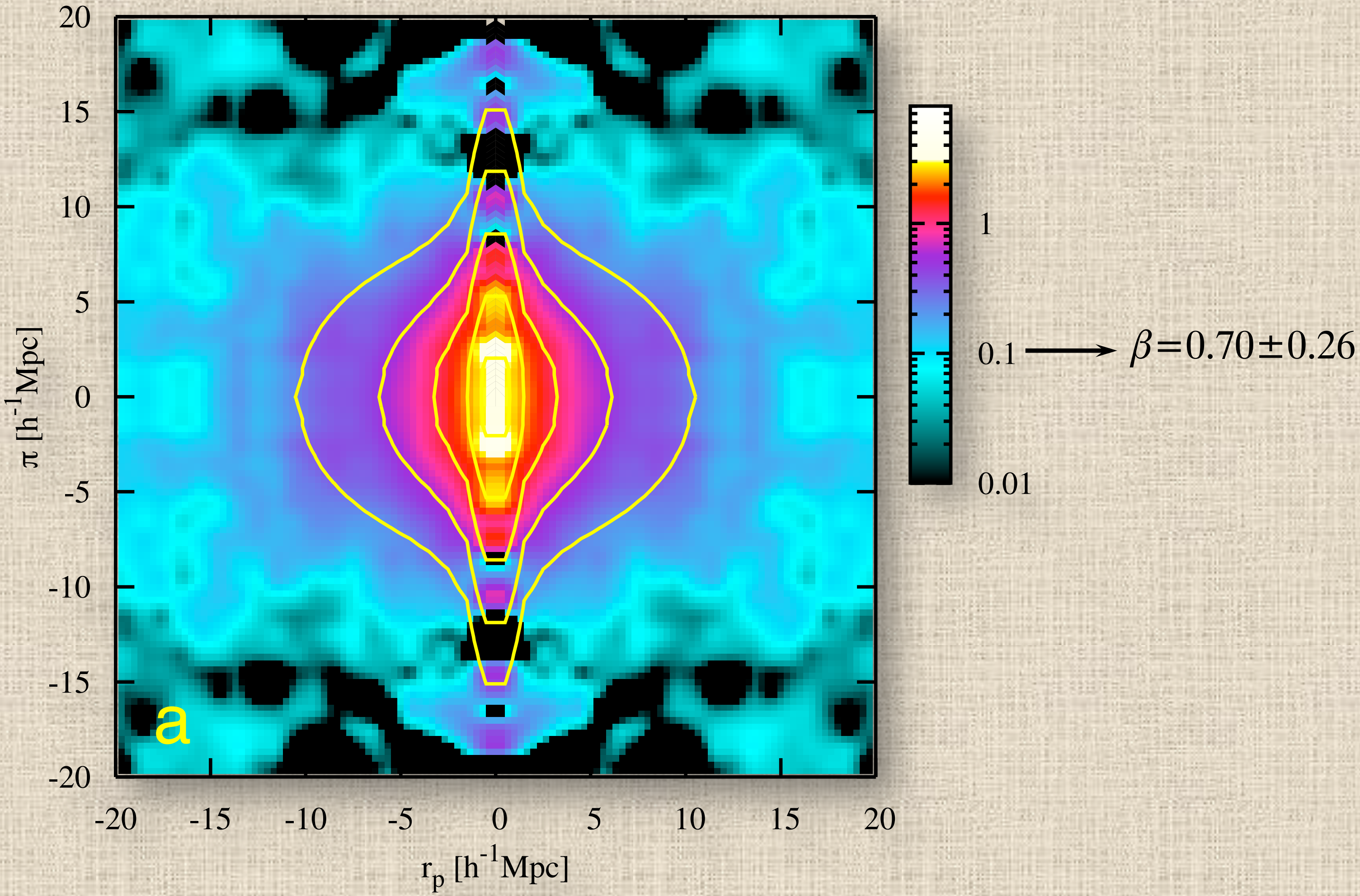


Compression parameter $\beta=0.49\pm0.09$

Peacock et al. 2001,
Hawkins et al. 2003

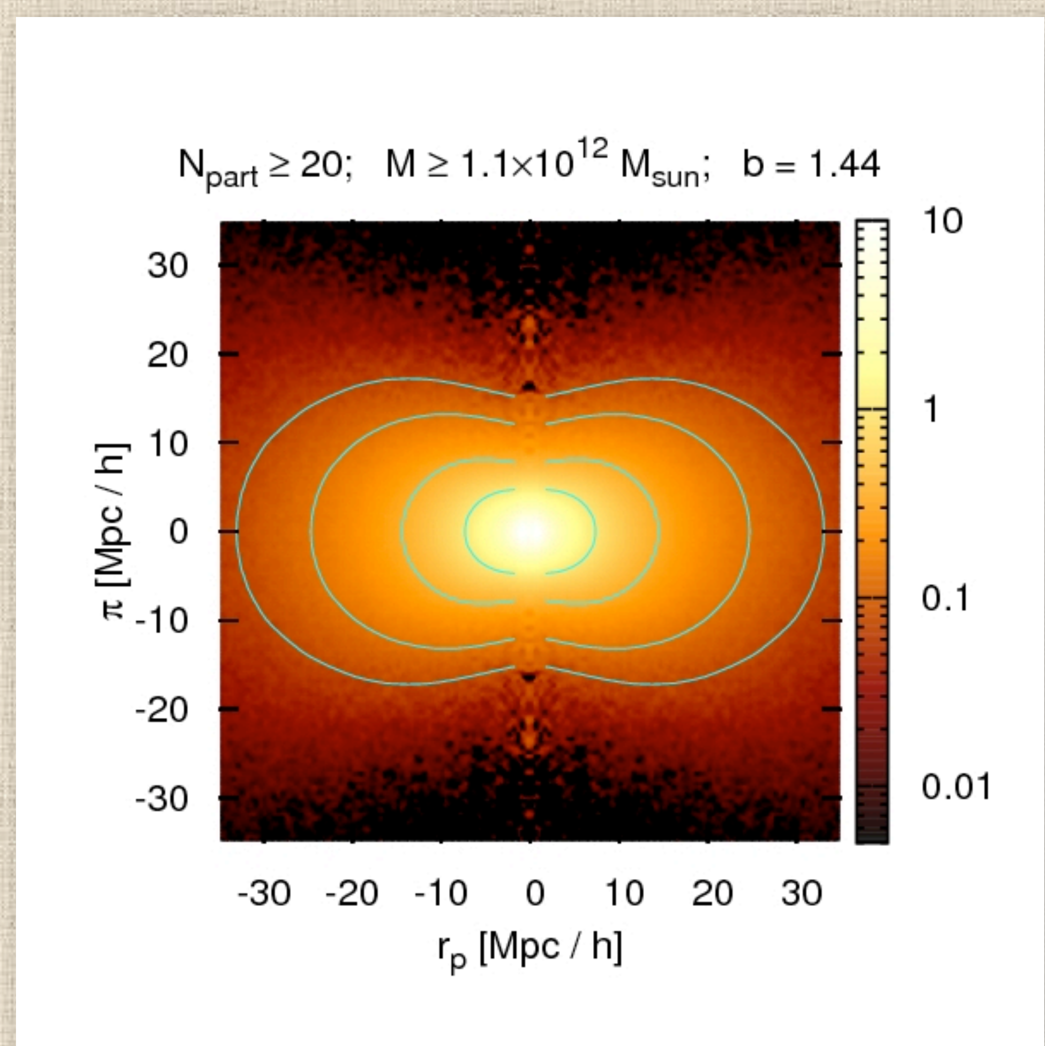
Redshift-space galaxy-galaxy correlation function $\xi(r_p,\pi)$

VVDS-Wide, z~0.8



Guzzo et al. 2008

$\xi(r_p,\pi)$ from <z>=1, dz=0.2 slice of EUCLID redshift survey

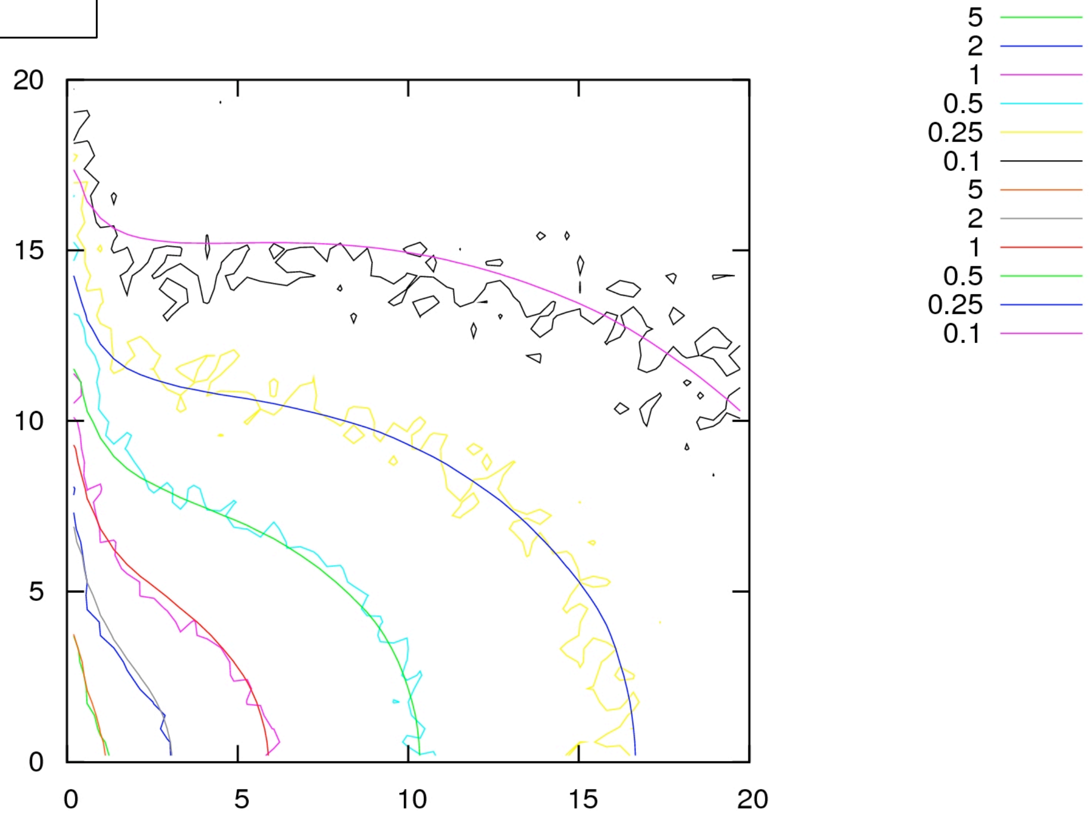


(D. Bianchi Master Thesis, using BASICC simulation)

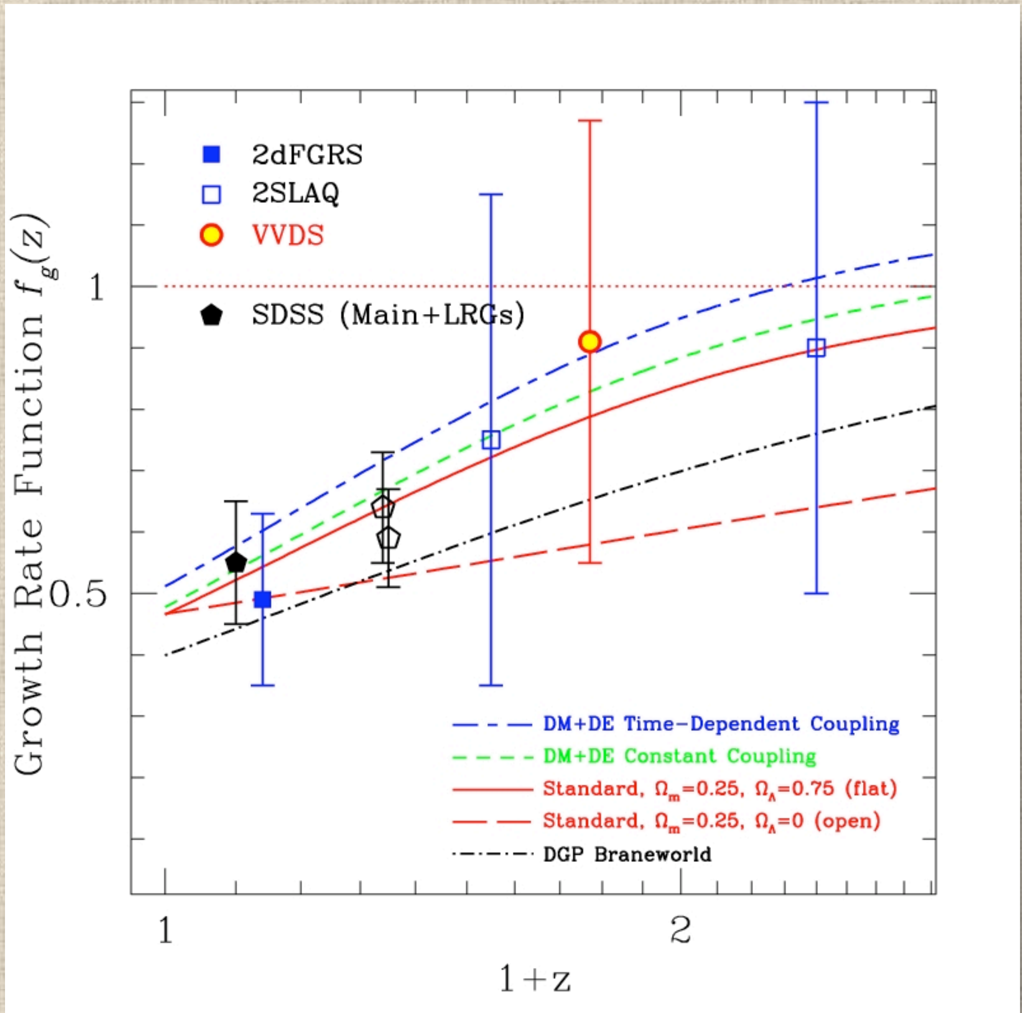
Extract β through Kaiser/Hamilton linear redshift-distortion model

$$P(k_{||}, k_{\perp}) = P(k)\left(1 + \beta\mu^2\right)^2 D(k\mu\sigma_p).$$

$$D(k\mu\sigma_p) = \frac{1}{1 + (k\mu\sigma_p)^2/2}$$



f(z) from redshift distortions: current status



$$f = b_L \beta$$

- 2dFGRS: Hawkins+ 2003
- SDSS main: computed from Tegmark+ 2005
- SDSS-LRG: Tegmark+ 2007, Cabre & Gaztanaga 2008 (see also Yamamoto+ 2008)
- 2SLAQ: Ross+ 2007 (gal), da Angela+ 2007 (QSO)

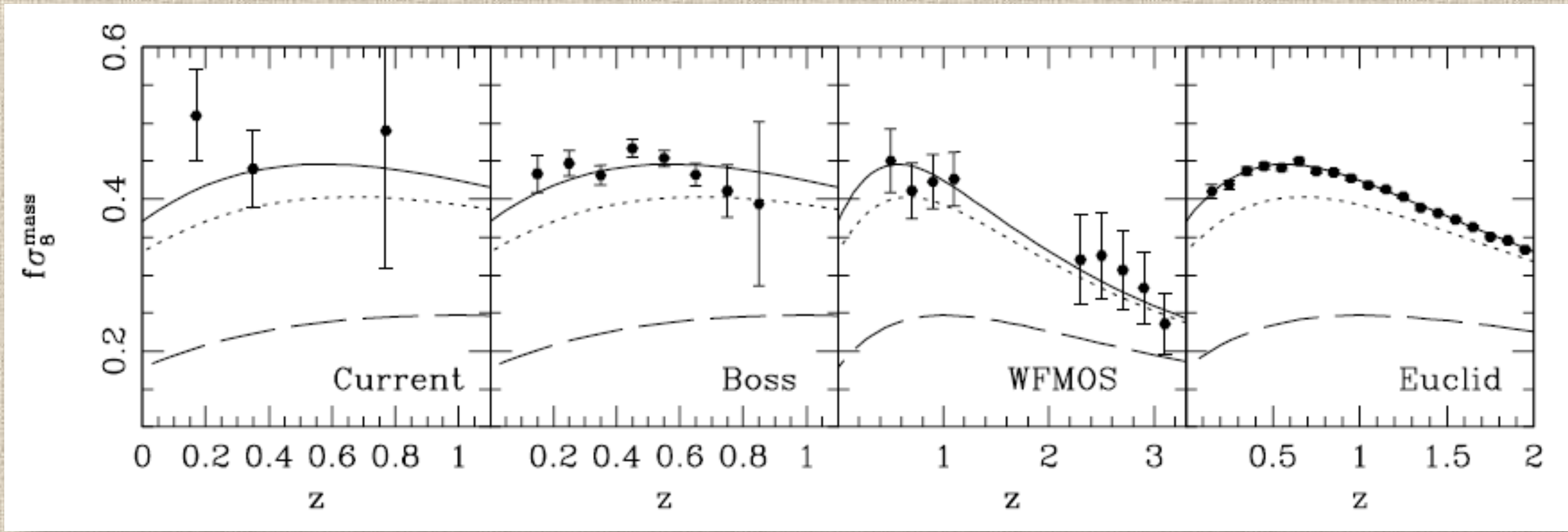
DGP: Lue et al. 2004; DM+DE models: Di Porto & Amendola 2007

What are redshift distortions probing in practice?

- Yeong-Song & Percival arXiv:0807.0810

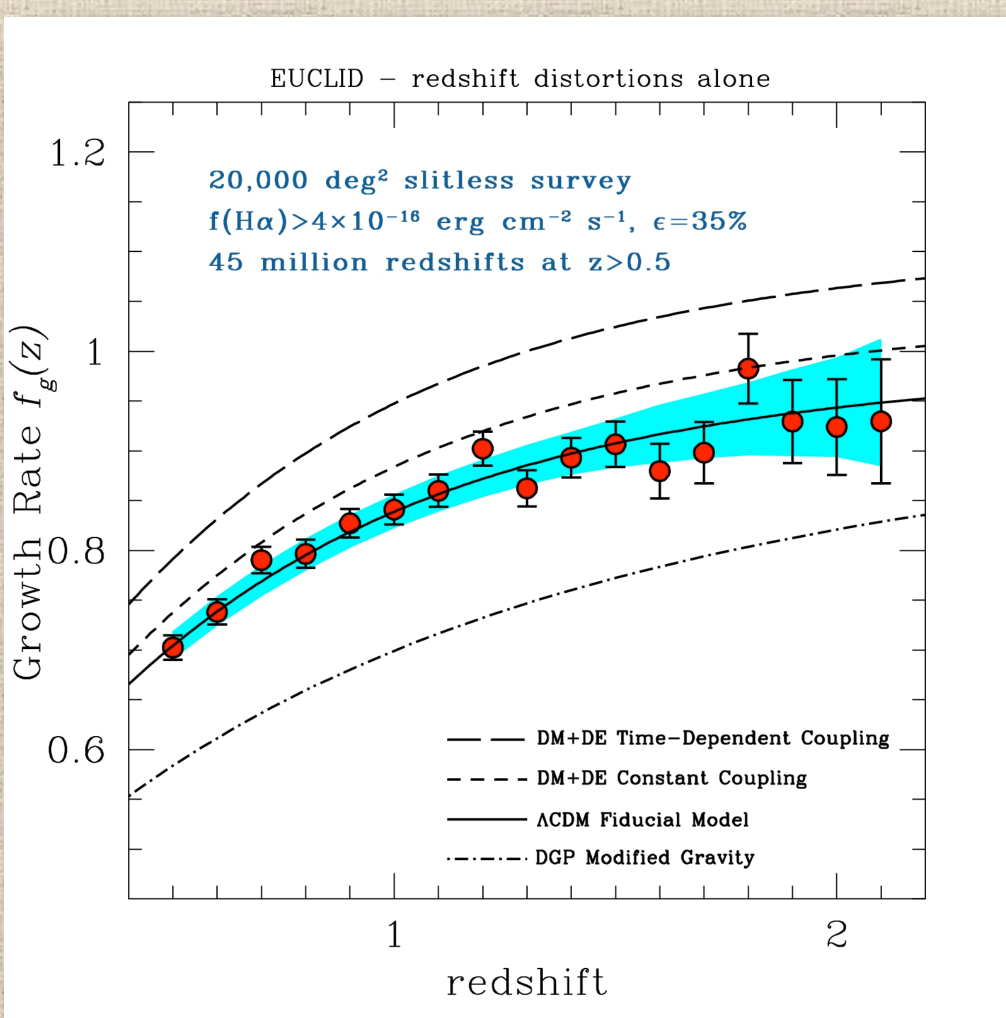
All from model (+CMB) *All observables*

$$f = b\beta \approx \frac{\sigma_8^{gal}}{\sigma_8^{mass}}\beta \quad \rightarrow \quad \boxed{F(z) = f(z)\sigma_8^{mass}(z) = \sigma_8^{gal}(z)\beta(z)}$$



- Percival and White arXiv:0808.0003

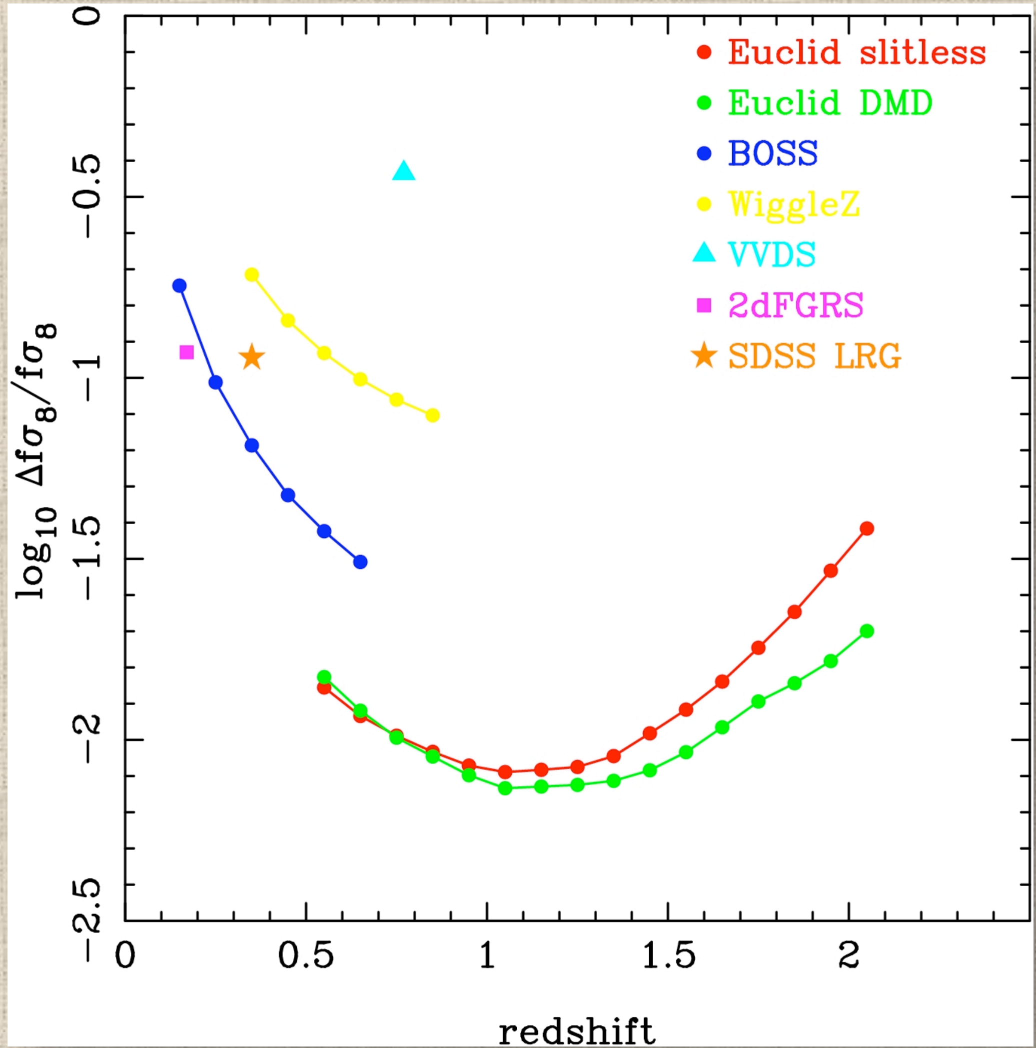
EUCLID redshift survey: f(z) from redshift-space distortions



Monte Carlo scaling-law forecast,
Guzzo et al. 2008

$$\frac{\sigma_\beta}{\beta} \approx \frac{A b_L}{V^{0.5} \langle n \rangle^{0.44}}$$

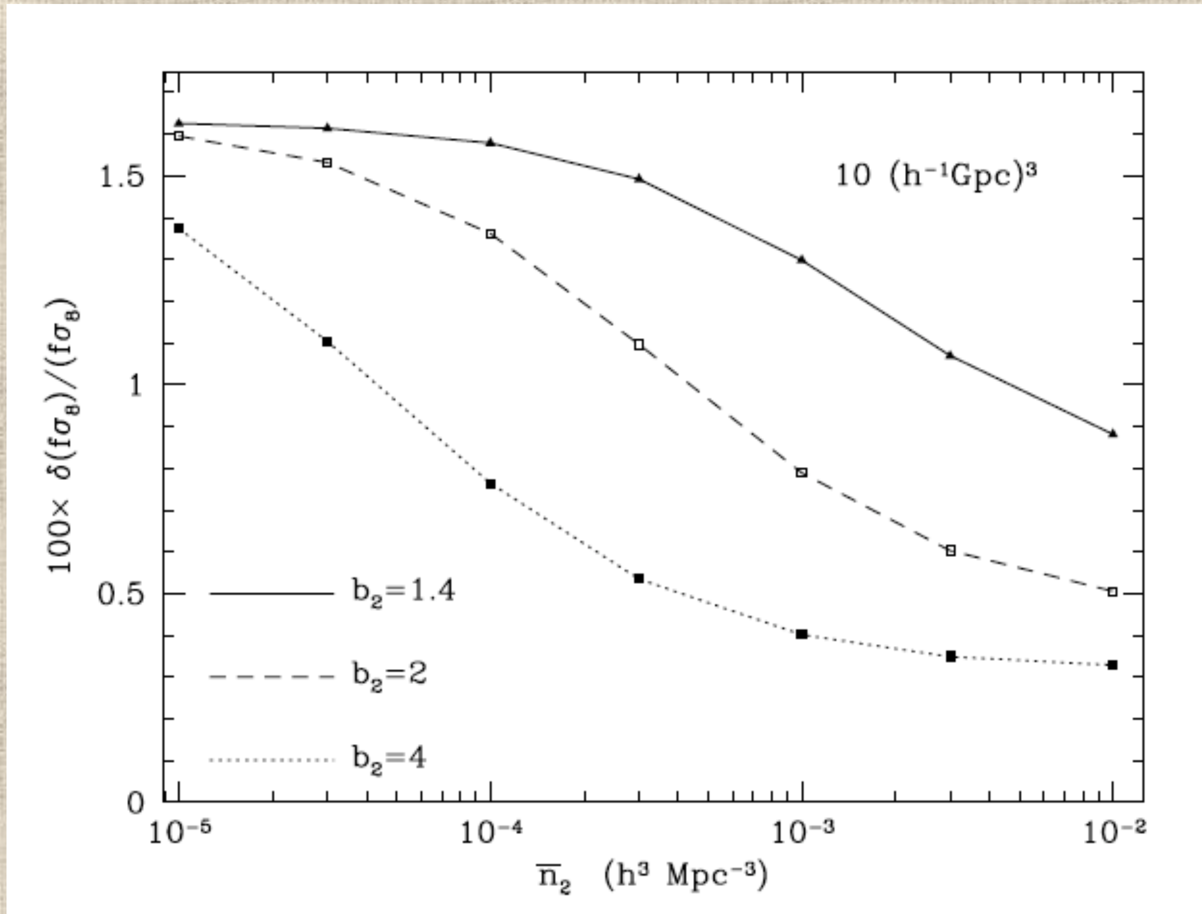
EUCLID redshift survey: f(z) from redshift-space distortions



One population only!

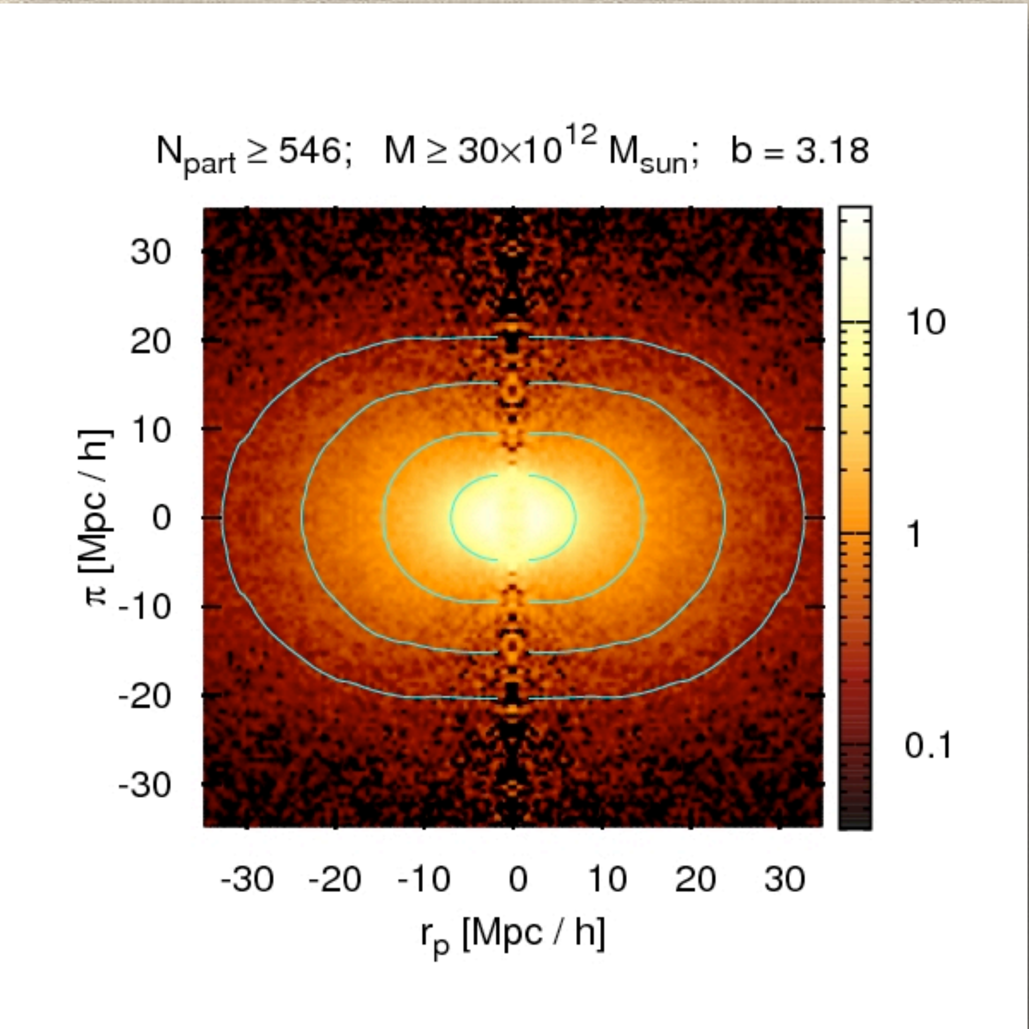
(Fisher matrix forecasts, W. Percival)

Abate cosmic variance on redshift distortions by using two populations of tracers with different bias (McDonald & Seljak 2009)



(White, Song & Percival 2008)

EUCLID redshift survey: distortions from tracers with different bias



EUCLID z~1 "galaxies"
$\langle n \rangle = 3\ 10^{-3}\ h^{-3}\ Mpc^{3}$

EUCLID z~1 "groups"
$\langle n \rangle = 3\ 10^{-4}\ h^{-3}\ Mpc^{3}$

EUCLID z~1 "clusters"
$\langle n \rangle = 5\ 10^{-5}\ h^{-3}\ Mpc^{3}$

(D. Bianchi Master Thesis, using BASICC simulation)

Summary

- Redshift-space distortions are emerging as a primary cosmological probe for future dark energy spectroscopic surveys: a lot of activity in the community
- Reaching the ~5% accuracy level on $\delta\beta/\beta = \delta(f\sigma_8)/f\sigma_8$ feasible with current linear modelling and understanding of non-linear effects
- Pushing to ~1% errors will require to:
  - Go beyond Kaiser linear model (e.g. Scoccimarro 2004; Tinker et al. 2006)
  - Further extend Monte Carlo tests to optimize survey parameters and model application (validating Fisher matrix forecasts under fully realistic conditions)
  - Explicitly evaluate actual gain when using multiple bias tracers (McDonald & Seljak 2009, see White et al. 2009)
  - Properly account Alcock-Paczynski effect (see e.g. Sapone & Amendola 2007, Simpson & Peacock 2009): indications are that huge EUCLID volume helps breaking degeneracy between dynamical and AP distortions
- Overall, these results indicate that EUCLID will be able measure f(z) using z-distortions to a few percent accuracy over a broad redshift range, making this a primary probe of the origin of cosmic acceleration