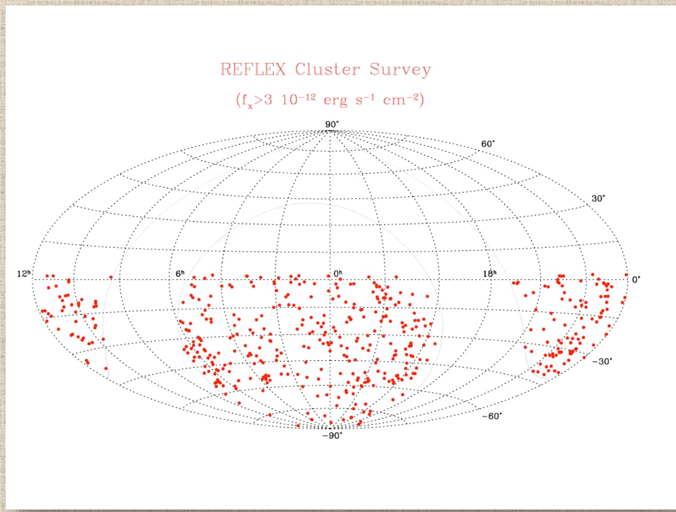
Cosmology with the cluster distribution and large-scale motions

Luigi Guzzo
(INAF - Osservatorio di Brera, Milano)

The (recent) past

REFLEX: the largest homogenous (nearly) all-sky survey of X-ray clusters constructed from the ROSAT All-Sky Survey

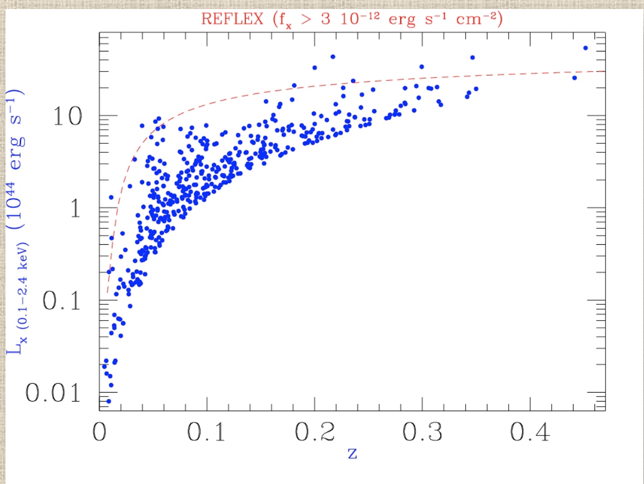
- $f_x < 3 \times 10^{-12}$ erg s^{-1} cm^{-2} (0.1-2.4 KeV)
- DEC<2.5°, |bII|>20° (4.24 sr)
- ~445 clusters



Boehringer et al. 2004; Guzzo et al. 2009

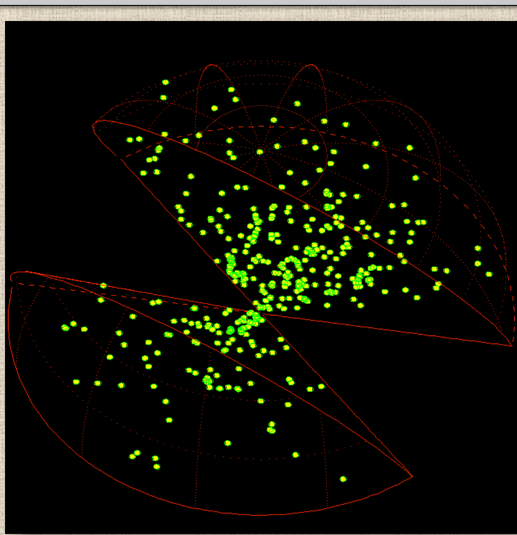
REFLEX: the largest homogenous (nearly) all-sky survey of X-ray clusters constructed from the ROSAT All-Sky Survey

- ESO Key Programme redshift follow-up (1992-2000)



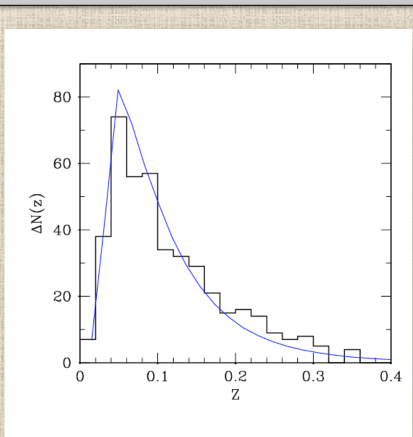
Boehringer et al. 2004; Guzzo et al. 2009

REFLEX: the large-scale distribution of galaxy clusters over ~1 Gpc scale

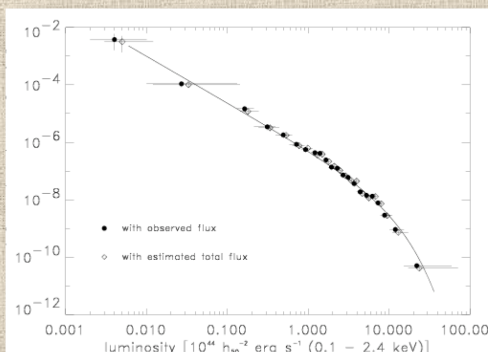


Boehringer et al. 2004; Guzzo et al. 2009

Cosmological content: (1) mean density of clusters above a given mass (1st moment)



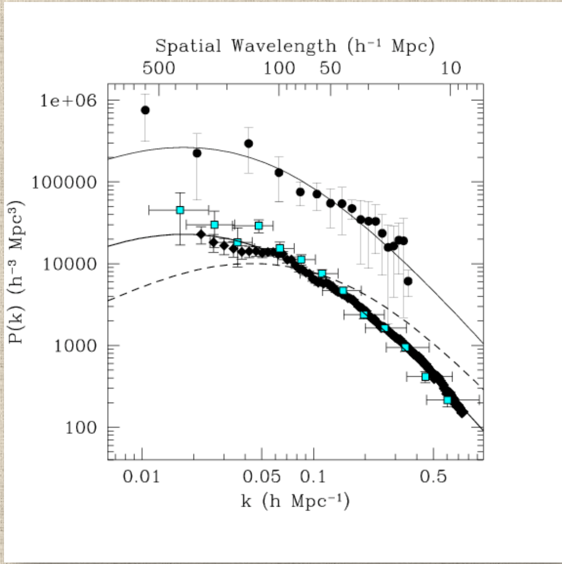
Schuecker et al. 2003



Depends on mean matter density Ω_m and rms amplitude of mass fluctuations σ_8

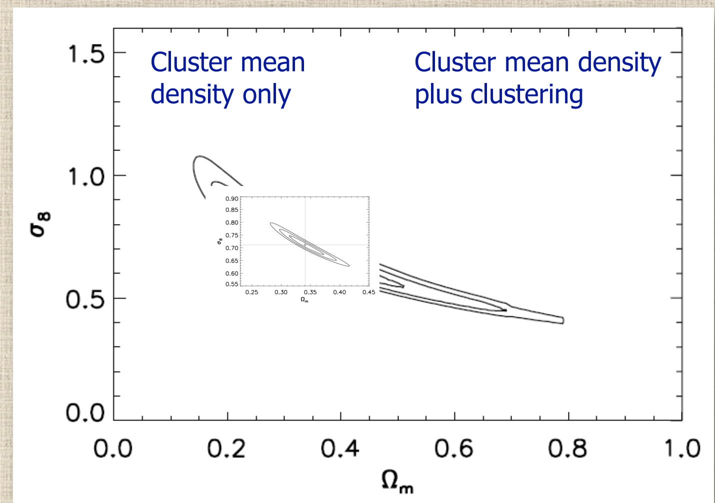
Boehringer et al. 2004

Cosmological content: (2) two-point correlation function or power spectrum (2nd moment)



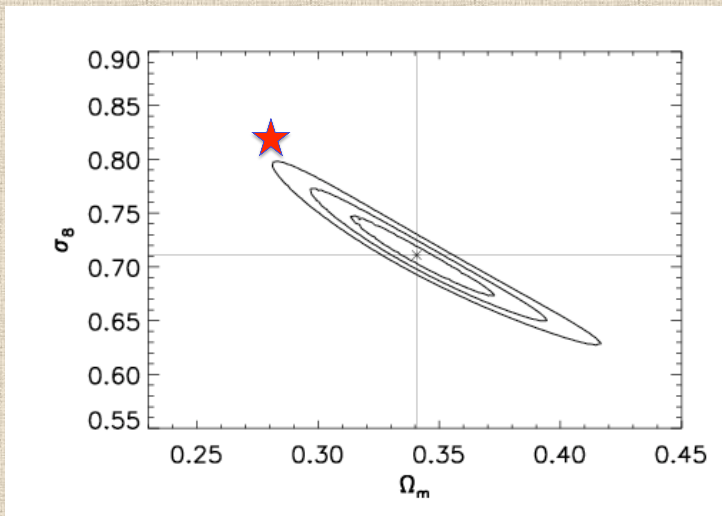
Schuecker et al. 2001, 2002, 2003; see also Borgani & Guzzo 2001

Cosmological parameters from REFLEX cluster number density and power spectrum (shape + amplitude)



Schuecker et al. 2004

Cosmological parameters from REFLEX cluster number density and power spectrum (shape + amplitude)

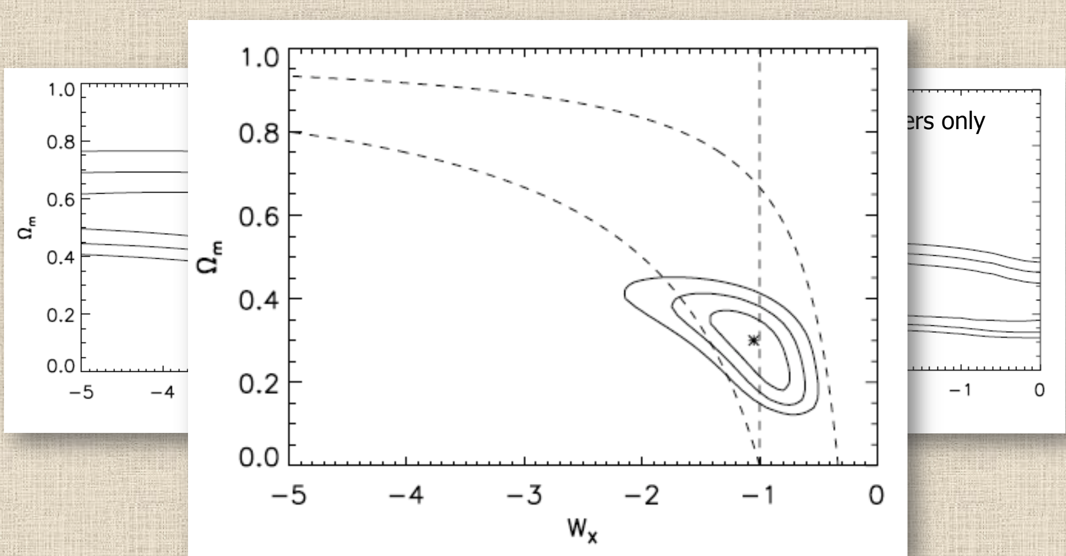


★ WMAP5 + BAO + Supernovae I

(Komatsu et al. 2009)

Schuecker et al. 2004

REFLEX: constraints on Dark Energy equation of state w



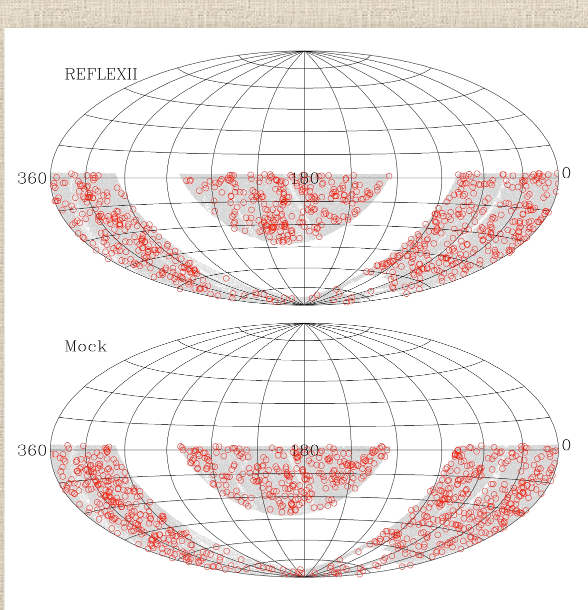
Schuecker et al. 2005

THE PRESENT

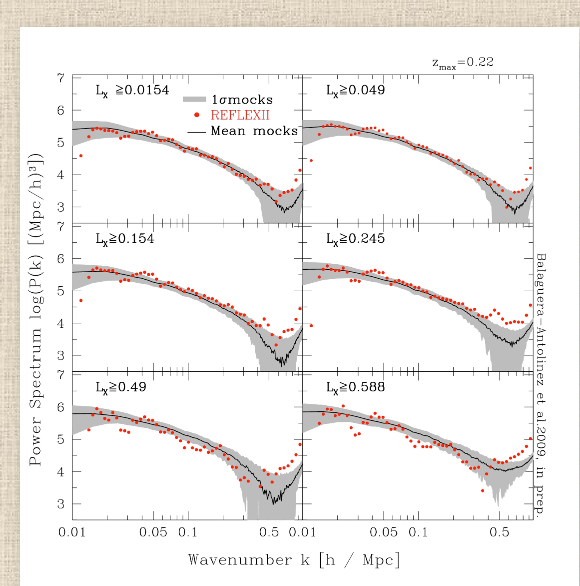
The enduring value of all-sky X-ray surveys: REFLEX-2

- H. Boehringer
- A. Balaguera-Antolinez
- A. Sanchez
- C. Collins
- GG

- $f_x < 1.8 \times 10^{-12}$ erg s^{-1} cm^{-2} (0.1-2.4 KeV)
- ~900 clusters
- Homogeneous xtension to Northern hemisphere ongoing



REFLEX-2: P(k)



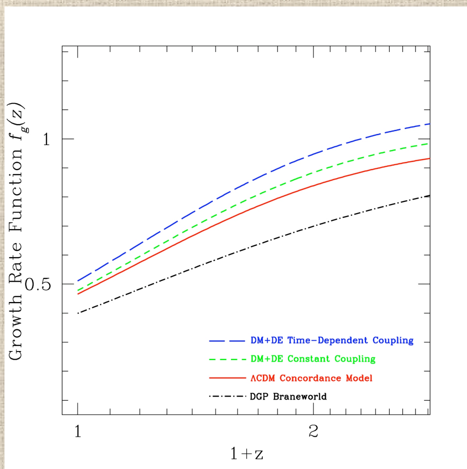
Balaguera-Antolinez et al. 2010; Sanchez et al. 2010

Large-scale motions of groups and clusters: measuring *f(z)* from redshift-space distortions

The dark energy / modified gravity degeneracy

- Cosmic acceleration can be reproduced either by adding dark energy into Einstein equations or by modifying the gravity theory (e.g. f(R) models, DGP)

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



How do we measure $f(z)$?

For a wide variety of models

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

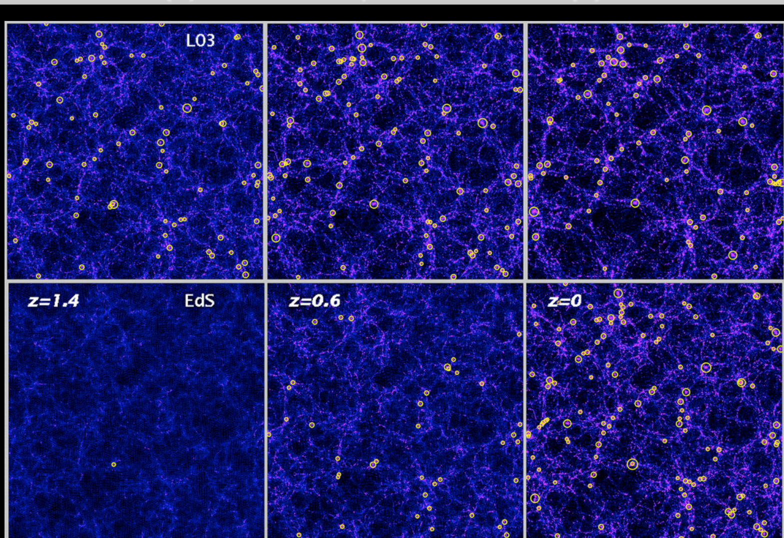
(Wang & Steinhardt 1998, Amendola et al. 2005, Linder 2005)

e.g.
$\gamma=0.55$ for standard Λ
$\gamma=0.68$ for DGP braneworld

The evolution of the cluster mean density probes a combination of the growth rate f(z) and the expansion rate H(z)

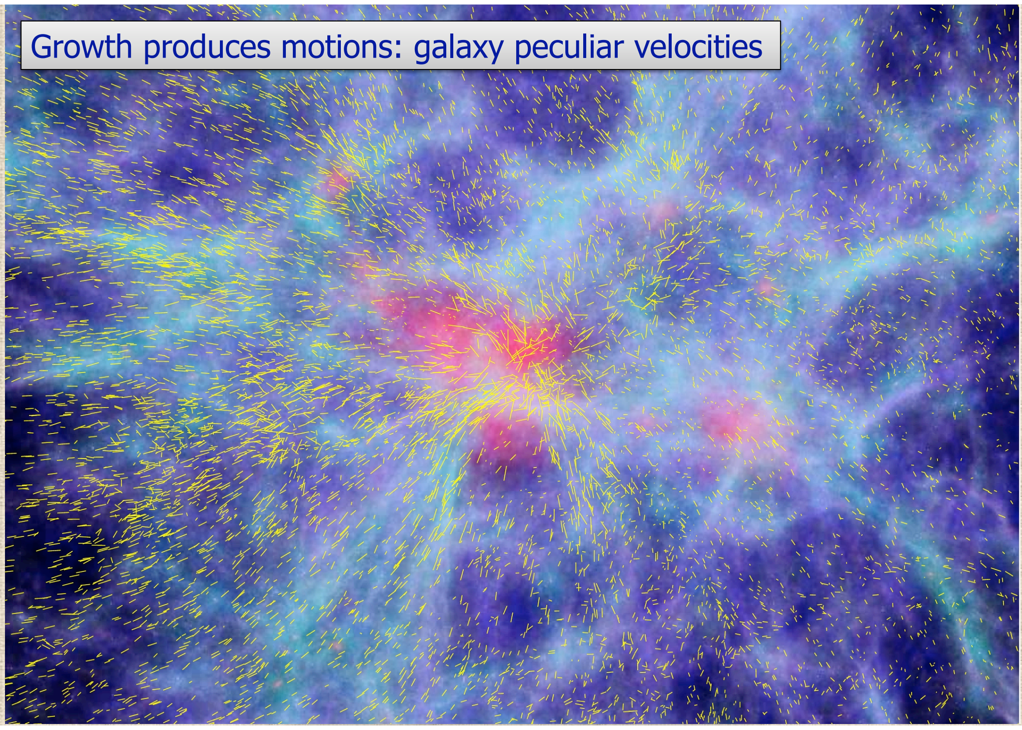
Lambda model

Einstein-DeSitter model



Borgani & Guzzo 2001

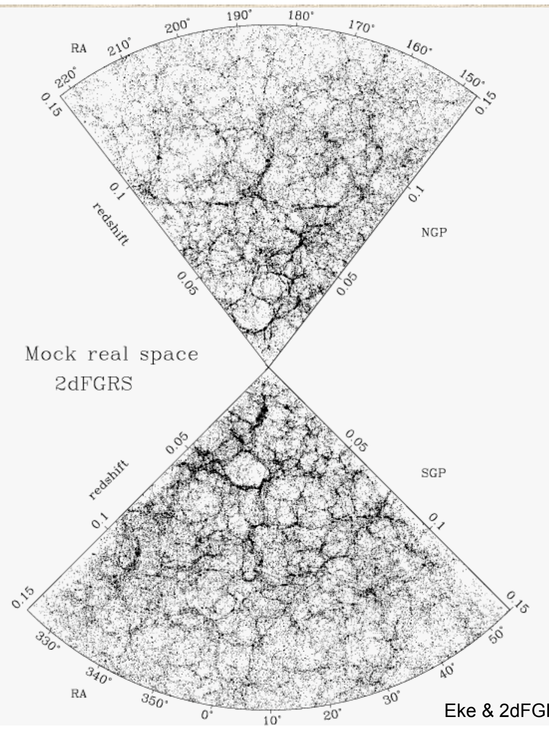
Growth produces motions: galaxy peculiar velocities



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

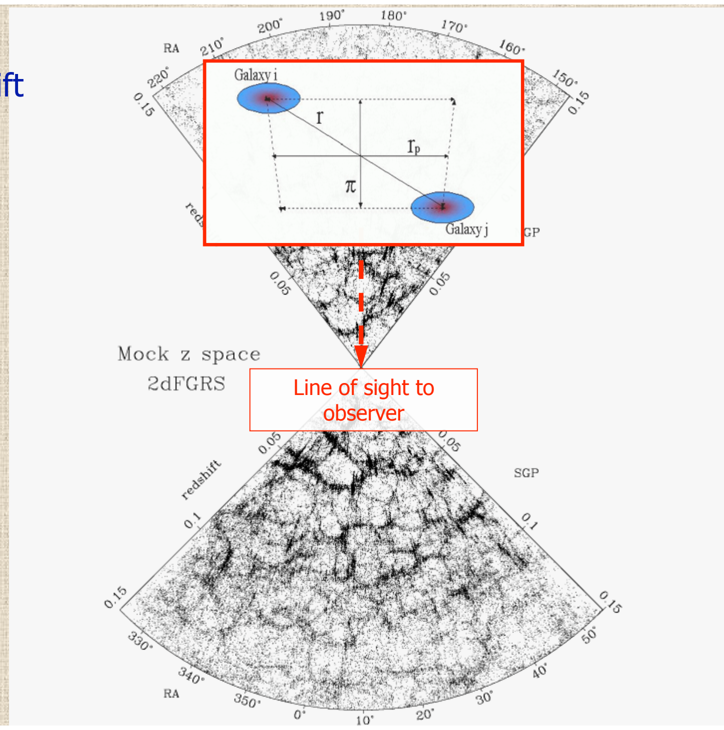
real space

(Kaiser 1987)



Eke & 2dFGRS 2003

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

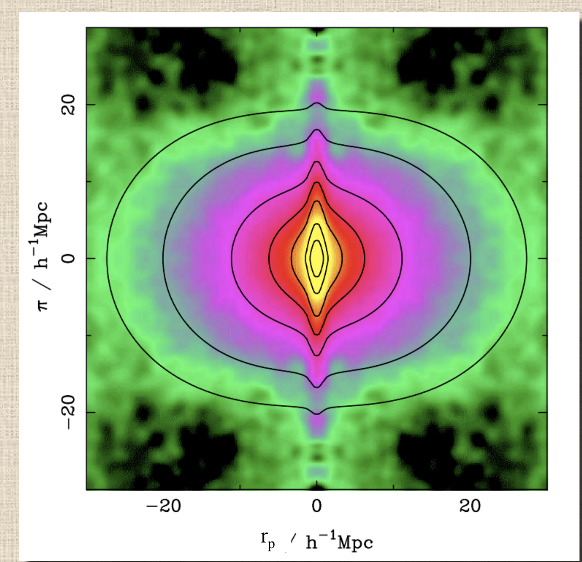


redshift space

(Kaiser 1987)

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

2dFGRS, z~0.1

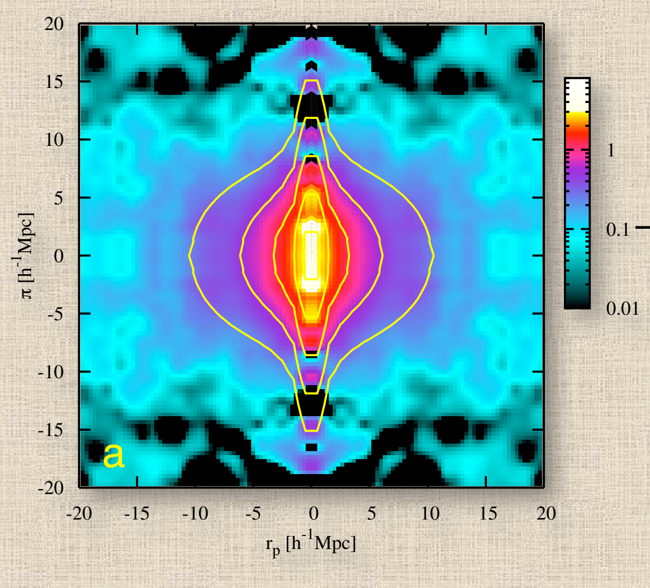


Compression parameter β=0.49±0.09

Peacock et al. 2001, Hawkins et al. 2003

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

VVDS-Wide, z~0.8



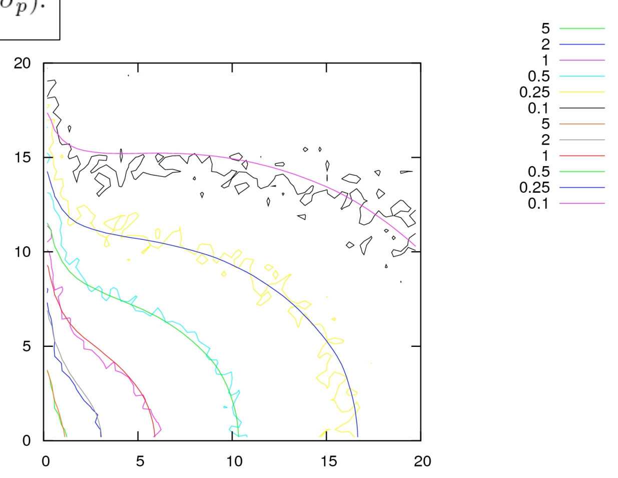
→ β=0.70±0.26

Guzzo et al. 2008

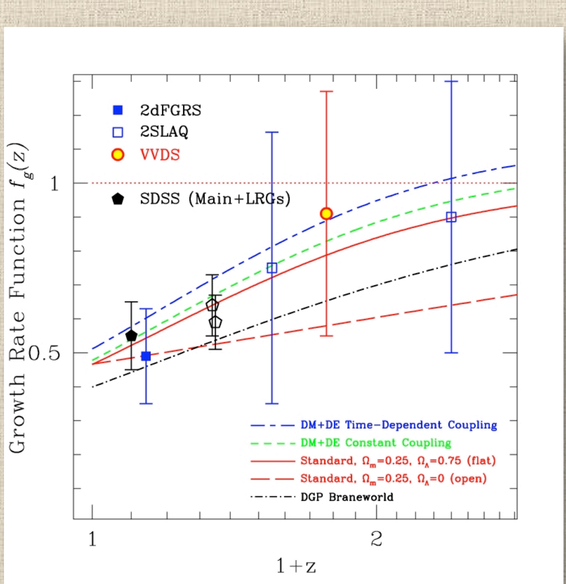
Extract β through Kaiser/Hamilton linear redshift-distortion model

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

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



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?

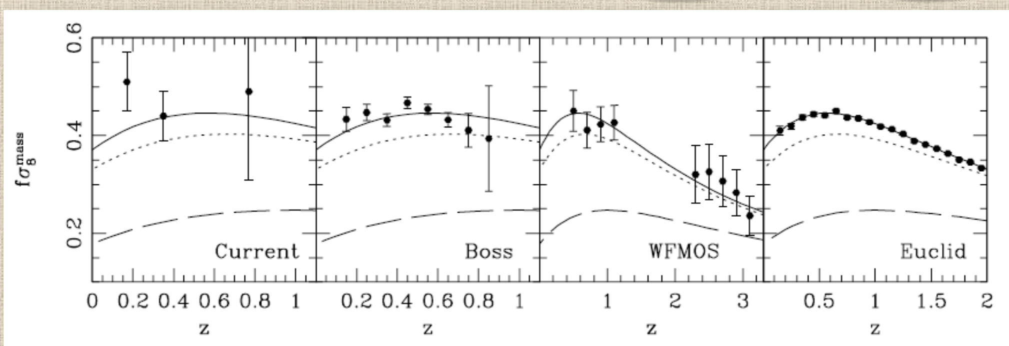
- Yeong-Song & Percival arXiv:0807.0810

All from model (+CMB) *All observables*

$$f = b\beta \approx \frac{\sigma_8^{gal}}{\sigma_8^{mass}}\beta$$

➔

$$F(z) = f(z)\sigma_8^{mass}(z) = \sigma_8^{gal}(z)\beta(z)$$

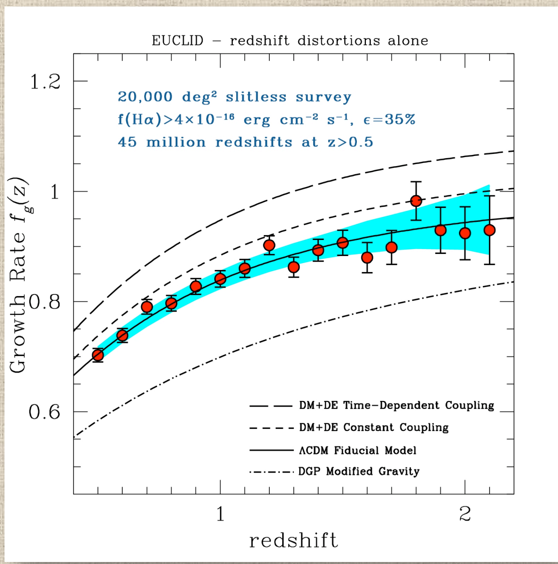


- Percival and White arXiv:0808.0003

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

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

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



One population only!

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

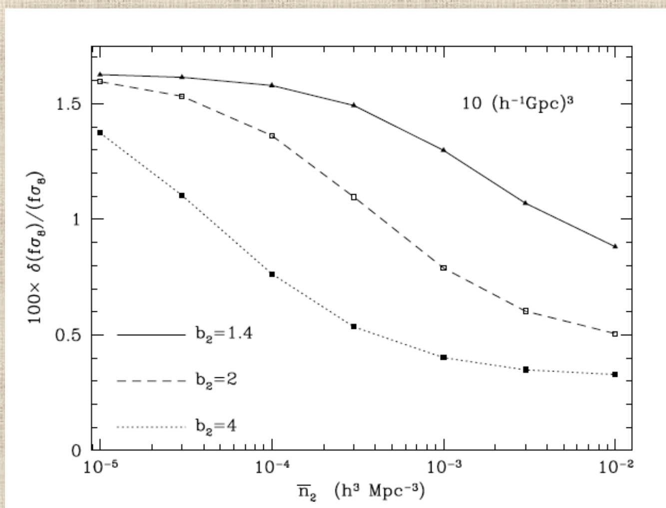
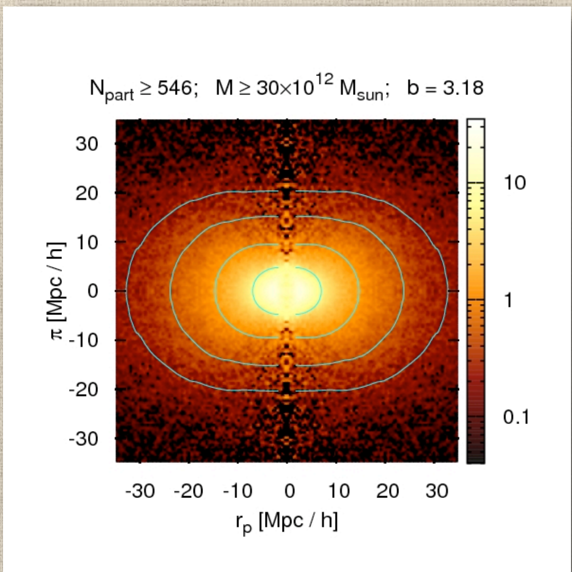


Figure from White et al. 2009

WFXT Wide Survey: distortions from tracers with different bias



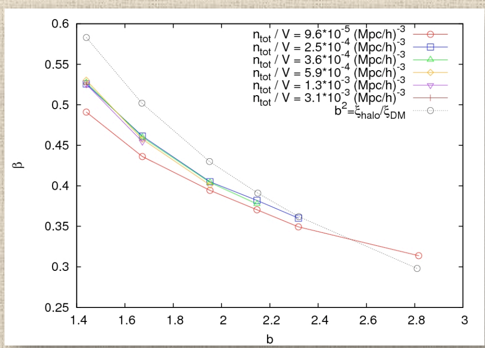
z~1 “galaxies”
<n>=3 $10^{-3}\ h^{-3}$ Mpc^3

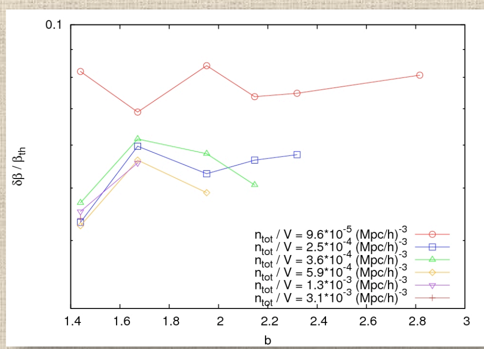
WFXT z~1 “groups”
<n>=3 $10^{-4}\ h^{-3}$ Mpc^3

WFXT z~1 “clusters”
<n>=5 $10^{-5}\ h^{-3}$ Mpc^3

(D. Bianchi Master Thesis, using BASICC simulation)

β and its error as a function of halo bias (i.e. cluster mass)





(Davide Bianchi et al., using BASICC simulation)

Summary

- X-ray large-area survey have a long-lasting impact: RASS still producing scientific results after >15 years
- Cosmology with X-ray clusters is alive and kicking: let's keep pushing
- It's amazing what we could do so far with a few hundred clusters only (REFLEX, but also with serendipitous surveys probing evolution – Rosati et al. 2002)
- In addition to abundance and clustering (and their evolution), probe the growth rate of structure measuring redshift-space distortions for groups and clusters:
  - Easier modelling: no non-linear motions (there are no Fingers of God of clusters!)
  - $\beta\sigma_8$ independent of mass-observable relation (dynamical constraint)
  - Select and combine easily objects with different bias to abate cosmic variance
- Caveats in using clusters for cosmology:
  - Combination of abundance and clustering gives constraints already dominated by systematics. Progress in understanding them is rapid (see Borgani's talk): eventually these will be understood and properly accounted for (no worse than weak lensing).
  - For z-distortions, many details to be explored (simulations, e.g. D. Bianchi thesis)
  - Cluster cosmology needs redshifts! How much can we do with WFXT clusters with X-ray-line z's? Are errors sufficient? What can we do with photo-z's (e.g. LSST)?
  - EUCLID would be the perfect complement to WFXT, providing cluster redshifts and weak lensing masses