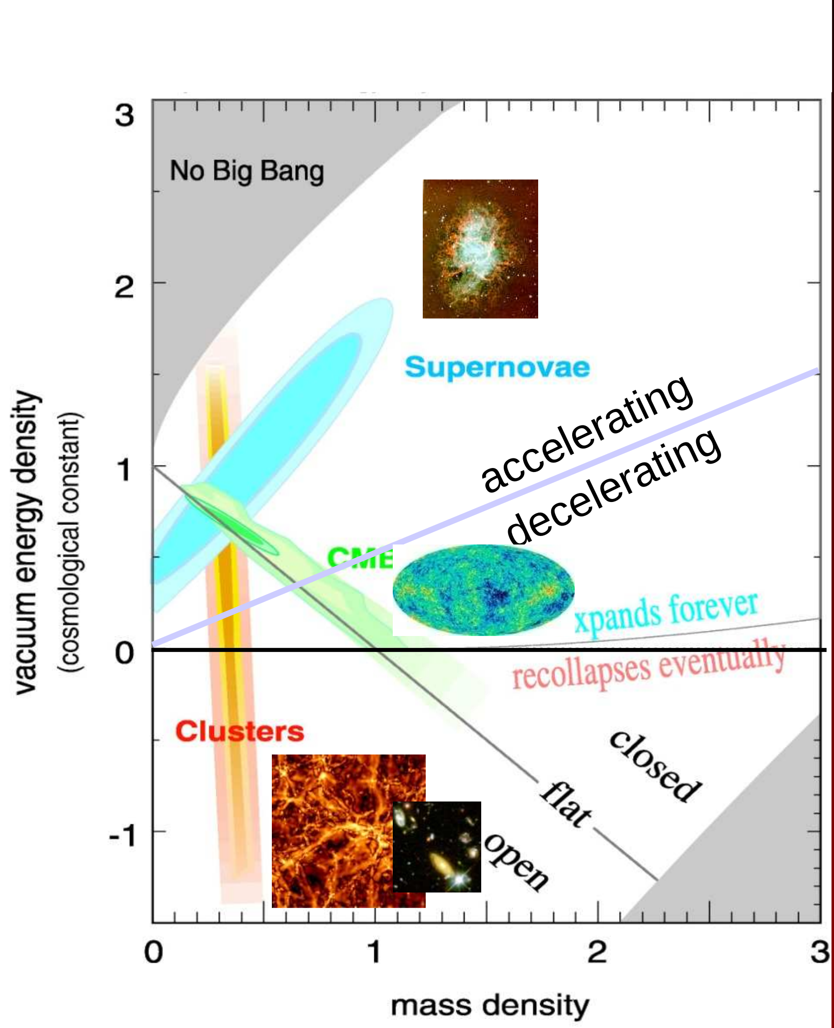
Testing gravity and cosmological models at z~1

Christian Marinoni

Université de Provence
Aix-Marseille I

State of the Art



Un unprecedented convergence of results in cosmology over the last few years are interpreted as follows

- ordinary matter is a minority (1/6) of all matter
- matter is a minority (1/4) of all energy
- geometry is spatially flat
- expansion is presently accelerated

Standard ΛCDM model!

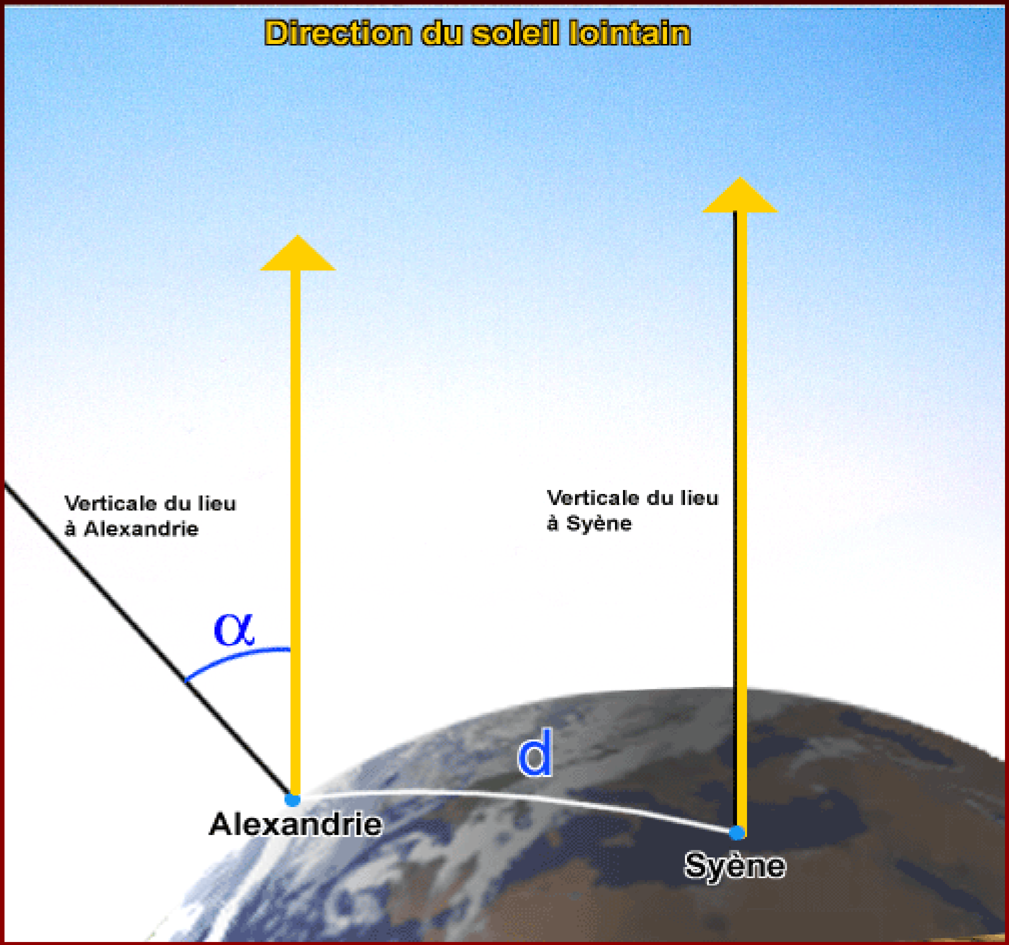
parameters precision
Vs.
hypotheses precision

Modified gravity is not particularly attractive theoretically, but the observed cosmic acceleration is so surprising that all plausible explanations should be considered.

Eratosthène et son modèle de la Terre (~ 220 av. JC)

Observations :

- Le jour du solstice d'été, à midi, le Soleil était au zénith à Syene et les objets n'avaient pas d'ombre
- Le même jours, a la même heure, les rayons du Soleil, faisaient un angle de 7° avec la verticale à Alexandrie



Hypothèses :

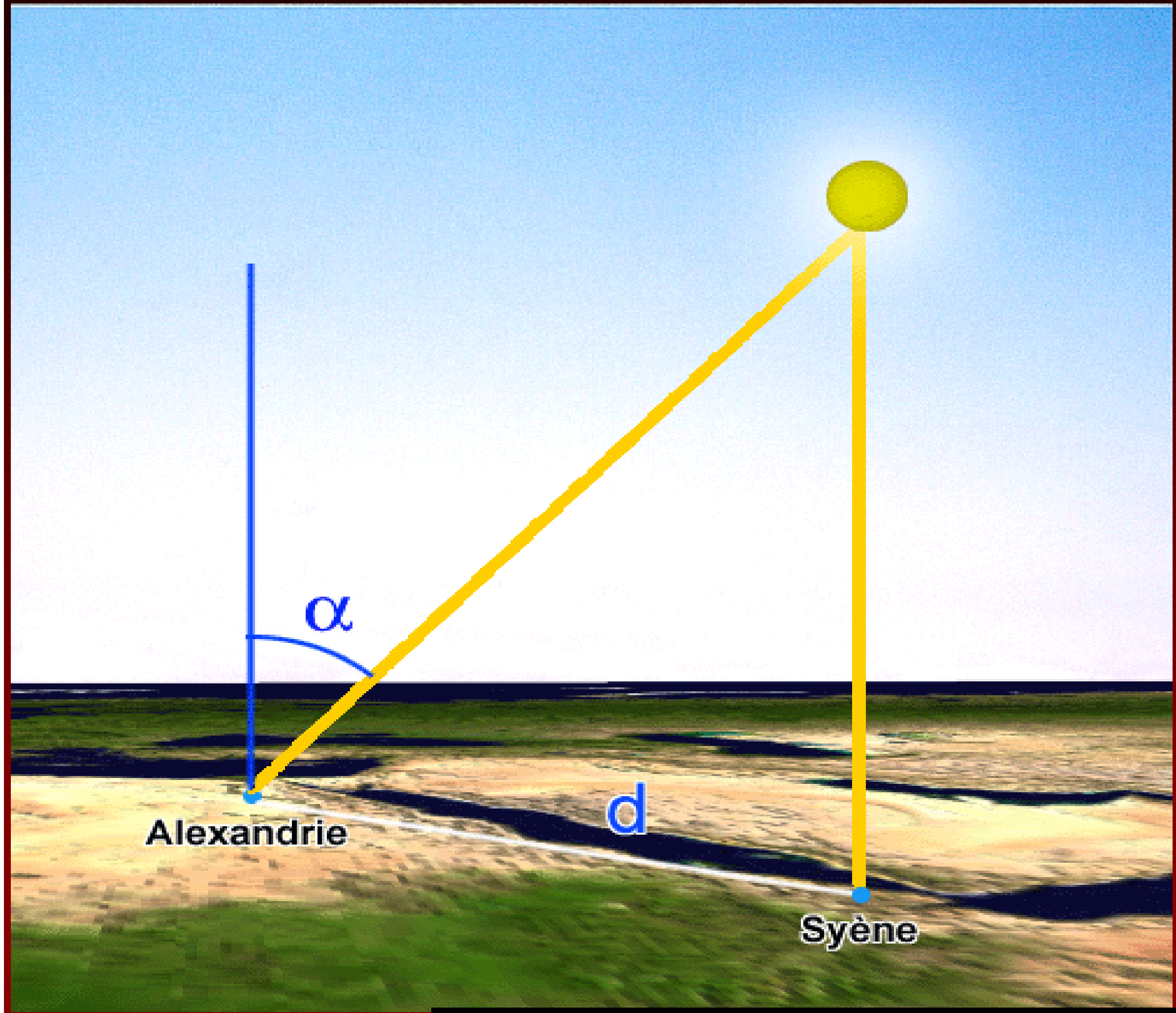
- La terre est ronde et les deux villes sont sur le même cercle maxime (méridien)
- le soleil était très éloigné de la Terre, de telle sorte que ses rayons arrivaient parallèlement entre eux

Conclusions :

rayon de la terre déterminé avec une précision de 3%

Anaxagore et son modèle du soleil (~430 av J.C)

Observations : les mêmes données de Ératosthène



Hypothèses :

- La Terre est plane
- Le soleil n'est pas trop loin (donc les rayons ne sont pas parallèles)

Marinoni et al. arXiv:0811.2358

Conclusions **« Le soleil est aussi grand que le Péloponnèse »**

This `*measurement*' is very precise, but it is very wrong!

Outline

- ***Testing Gravity at z=1***

  - <u>with 2nd order statistics</u> :

  - redshift evolution of the linear growth rate of density fluctuations

  - <u>with 3rd order statistics</u> :

  - Redshift evolution of the skewness of the galaxy density fluctuations

- ***Measuring cosmological parameters***

  - The cosmological lensing of galaxy diameters

  - Counts of deep optical clusters VVDS+DEEP2

The Linear Growth Rate Function

- **Linear Regime (δ<<1)**
- **Newtonian Approximation (P<<ρ)**
- **Dark matter is pressureless (dP=0)**
- **Adiabatic perturbations (dσ=0)**

$$\frac{\partial \delta}{\partial \tau} + \theta = 0$$

$$\frac{\partial \theta}{\partial \tau} + \mathrm{H}\theta = -4\pi G \rho \delta$$

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

$$\theta \equiv \nabla_x \cdot v$$ ← Velocity perturbations

These two scalar fields (the density contrast and the divergence of the perturbed velocity field) completely specify the inhomogeneous universe at linear order

$$\frac{\partial^2 \delta}{\partial^2 \tau} + \mathrm{H}\frac{\partial \delta}{\partial \tau} = 4\pi G a^2 \bar{\rho}^t \delta^t$$

$$\delta(x,t) = D_+(t)\delta(x,t_i)$$

Growing mode

$$\vec{v}(\vec{x},t) = -\frac{\mathrm{H}(\tau) f(\tau)}{4\pi} \int \delta(\vec{x}',\tau) \frac{(\vec{x}-\vec{x}')}{|\vec{x}-\vec{x}'|^3} d^3x'$$

$$f = \frac{\partial \ln D_+(t)}{\partial \ln a}$$

Growth Rate

Important info about
- Cosmological parameters
- Nature of gravity
- Initial conditions

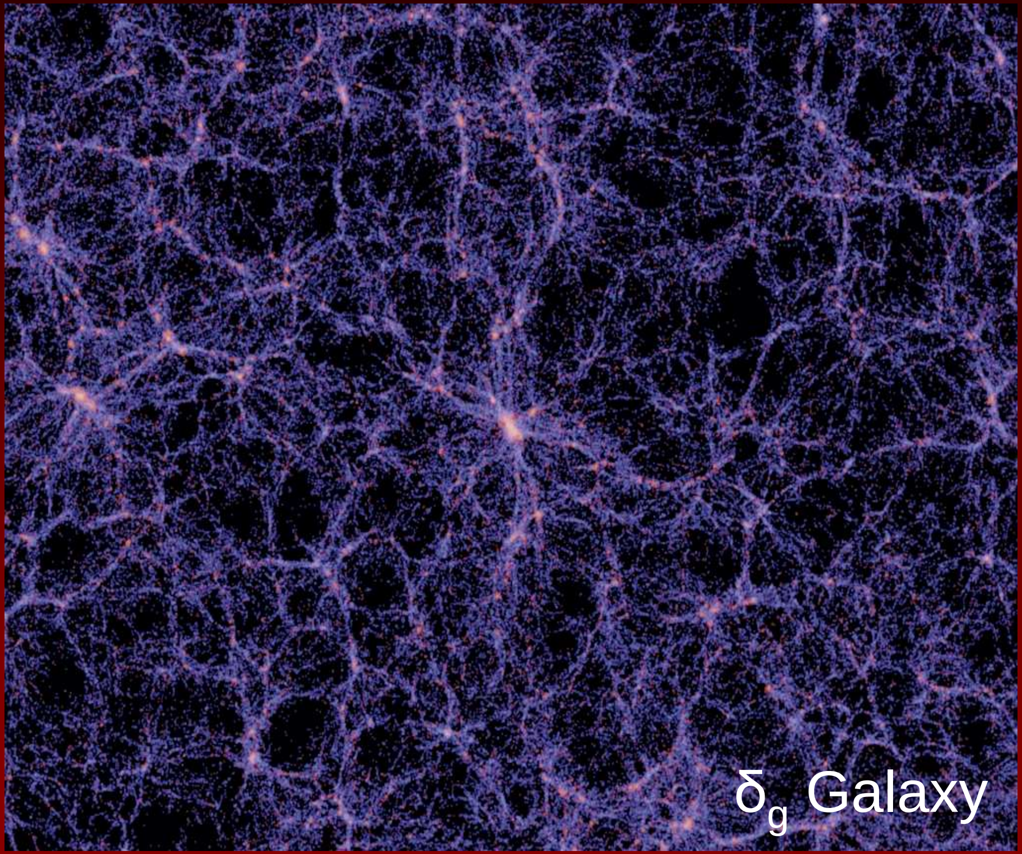
Actually the observable is δ_g

The biasing problem

$$\delta_g = \sum_k \frac{b_k}{k!} \delta^k$$

Biaising

Millenium Simulation



Springel et al. Nature 2005

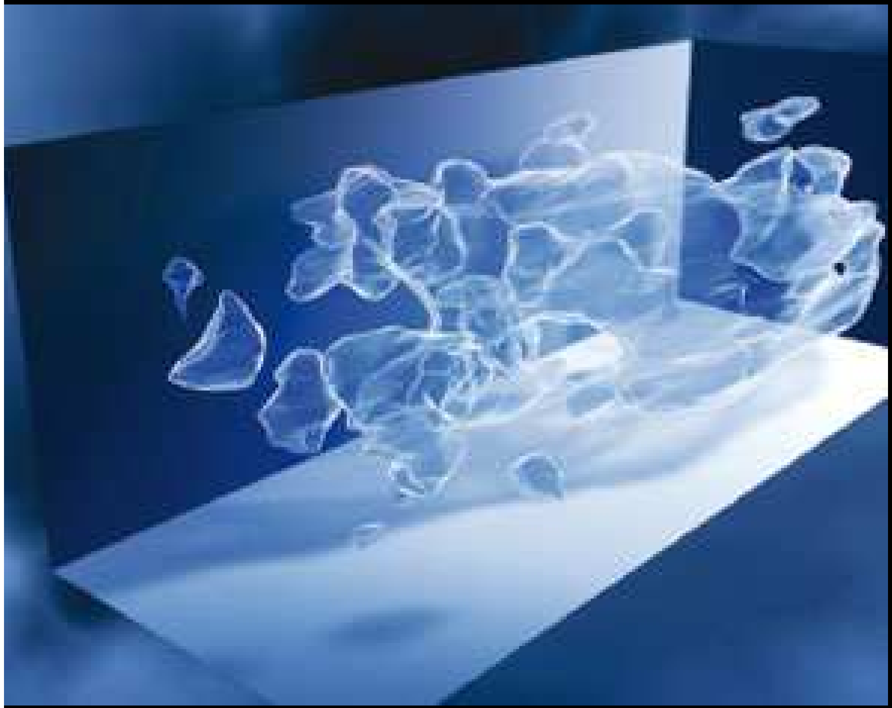
- Formal Problem

$$\delta_g = \delta_g(\delta, z)$$

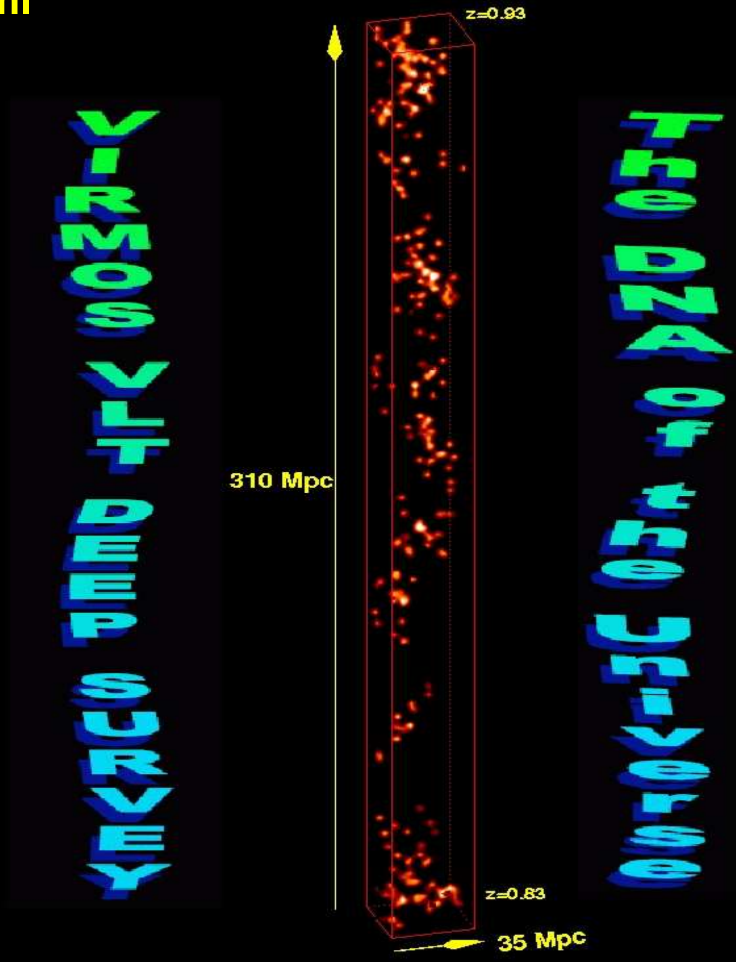
Bais
Fundamental variable which allows us to compare
theory and observations

Massey et al. 2007 (ACS/COSMOS)

www.spacetelescope.org/news/html/heic0701.html



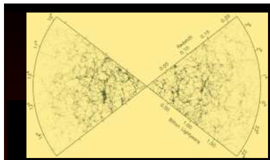
Mass Fluctuations



Galxy Fluctuations

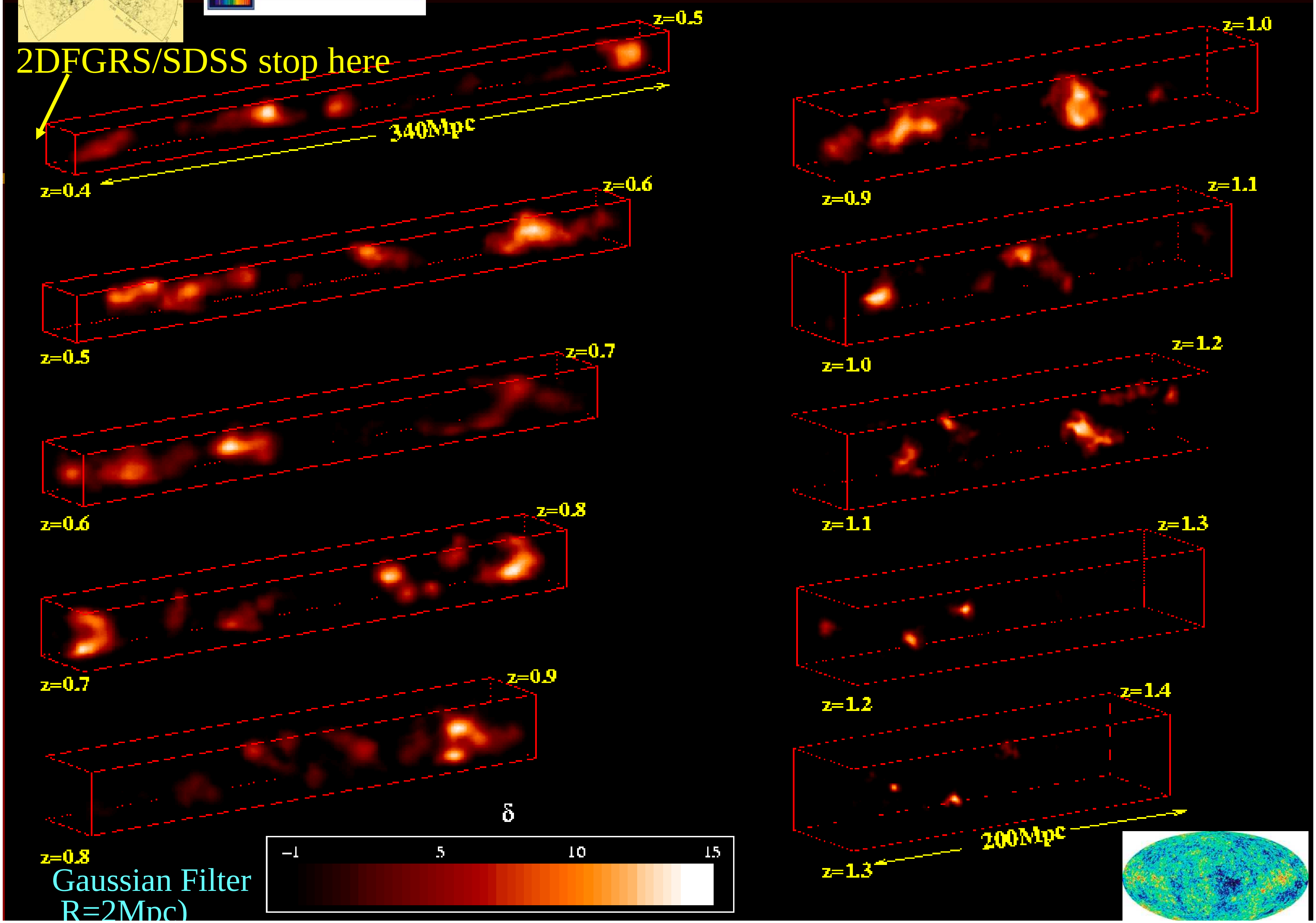
Marinoni et al. 2008 (VIMOS/VLT)

http://www.eso.org/outreach/press-rel/pr-2007/pr-45-07.htm

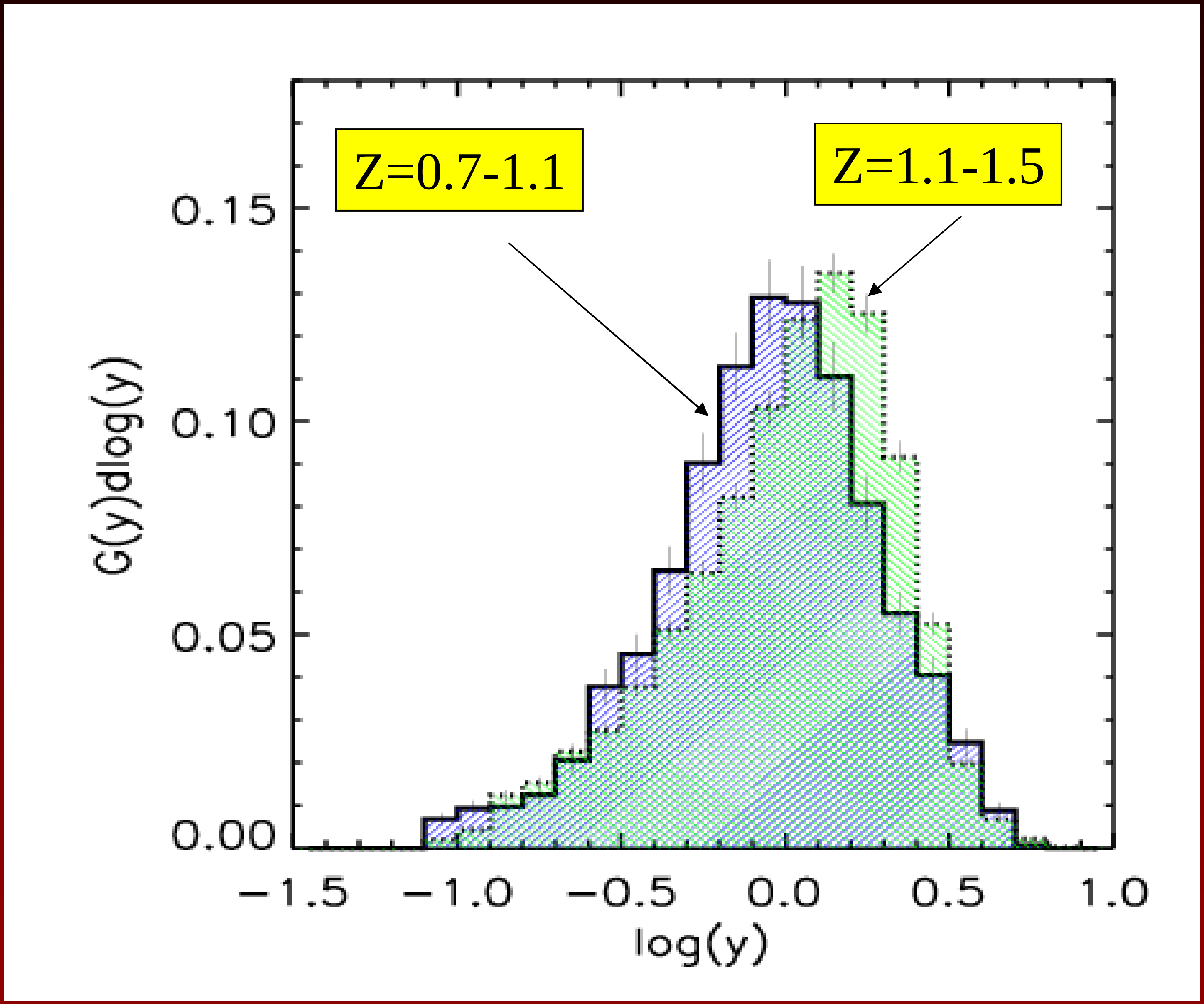


δ Field

Marinoni et al. 2008 A&A

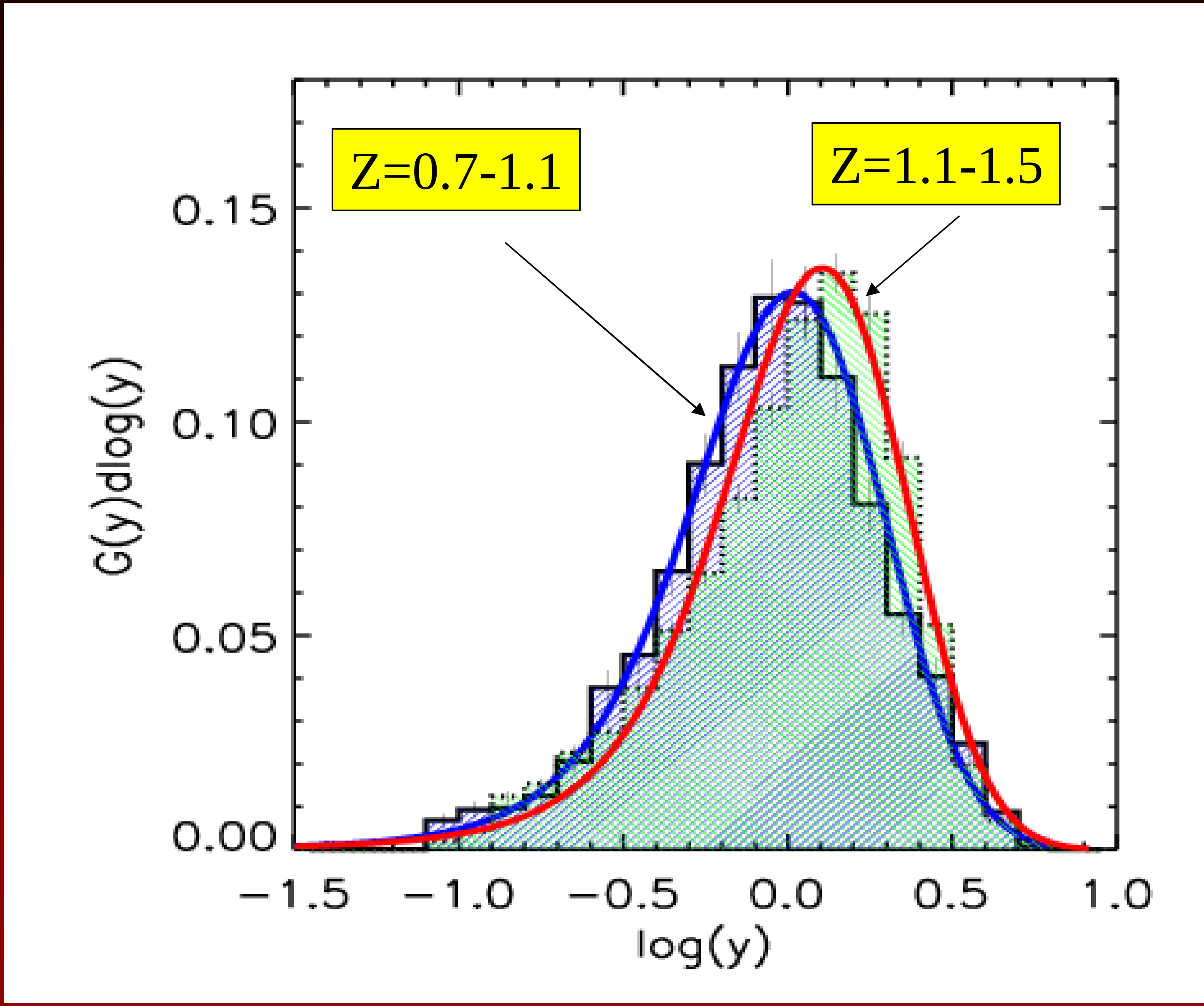


The PDF of galaxy overdensities g(δ): Shape



Prédiction of the form of the biasing function

Marinoni et al. 2005, A&A, 442, 801



$$g(\delta_g)d\delta_g = \varphi(\delta)d\delta$$

$$\delta_g = \delta_g(\delta)$$

Bias is not linear !

(Fry & Gaztanaga 1993)

$$\delta_g = \sum_k \frac{b_k}{k!}\delta^k$$

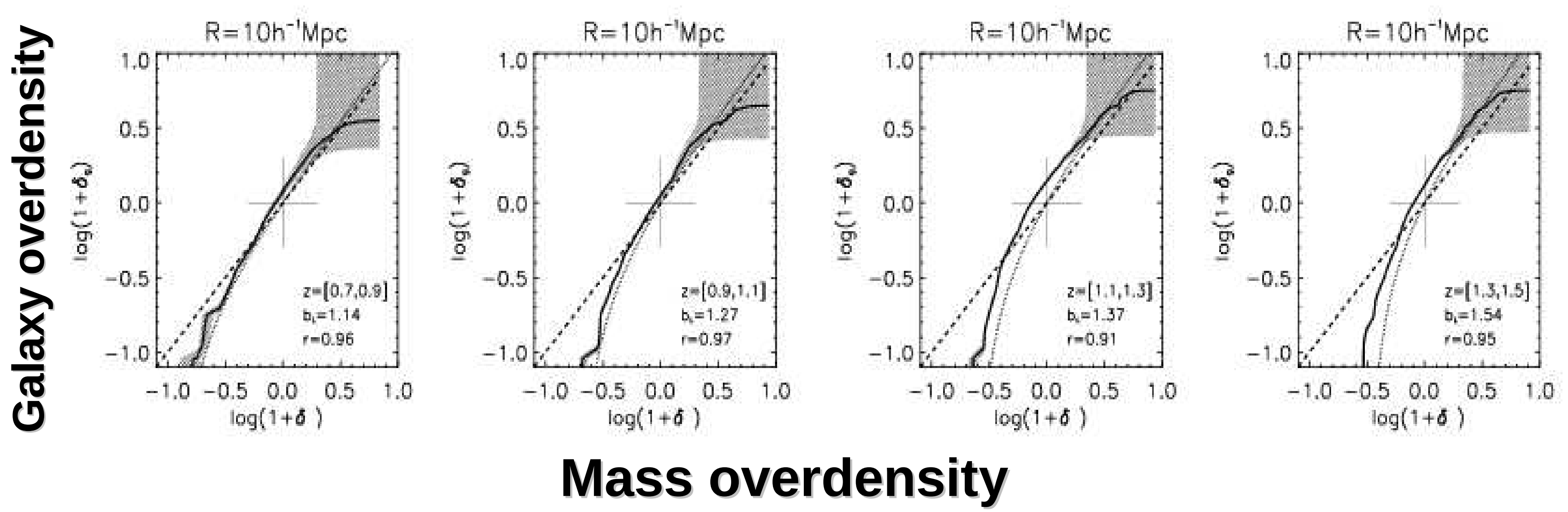
$$\left\langle \frac{b_2}{b_1} \right\rangle = -0.19 \pm 0.04$$

The biasing function: Shape

The VVDS Measurements

Volume limited sample (M<-20+5log h)

z



- **Non linearity at a level 3% on scales 5<R<10 Mpc** Marinoni et al 2005
  (Local slope is steeper (bias stronger) in underdense regions)

$$\delta_g = \sum_k \frac{b_k}{k!}\delta^k \qquad \left\langle \frac{b_2}{b_1} \right\rangle_{z=[0.6-1.4]} = -0.19 \pm 0.04$$

- **At recent epochs luminous galaxies form also in low density regions, while at high z the formation process is inhibited in under-densities**

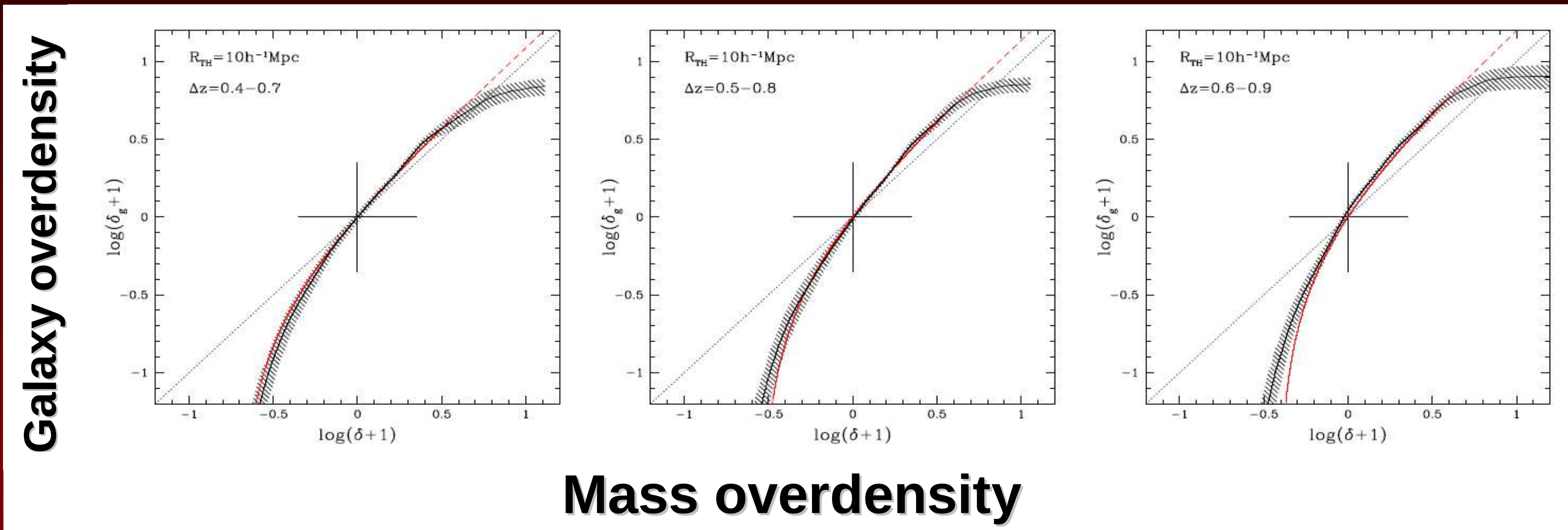
The biasing function: Shape

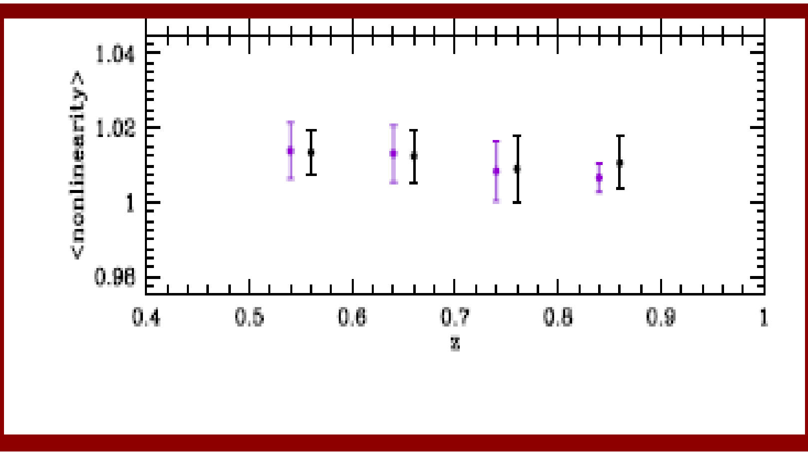
The Zcosmos measures

(FoV=1.7deg^2 , 10.000 redshifts, I<22)

Volume limited sample (M<-20-z)

Z





Kovac et al. 2009 in prep

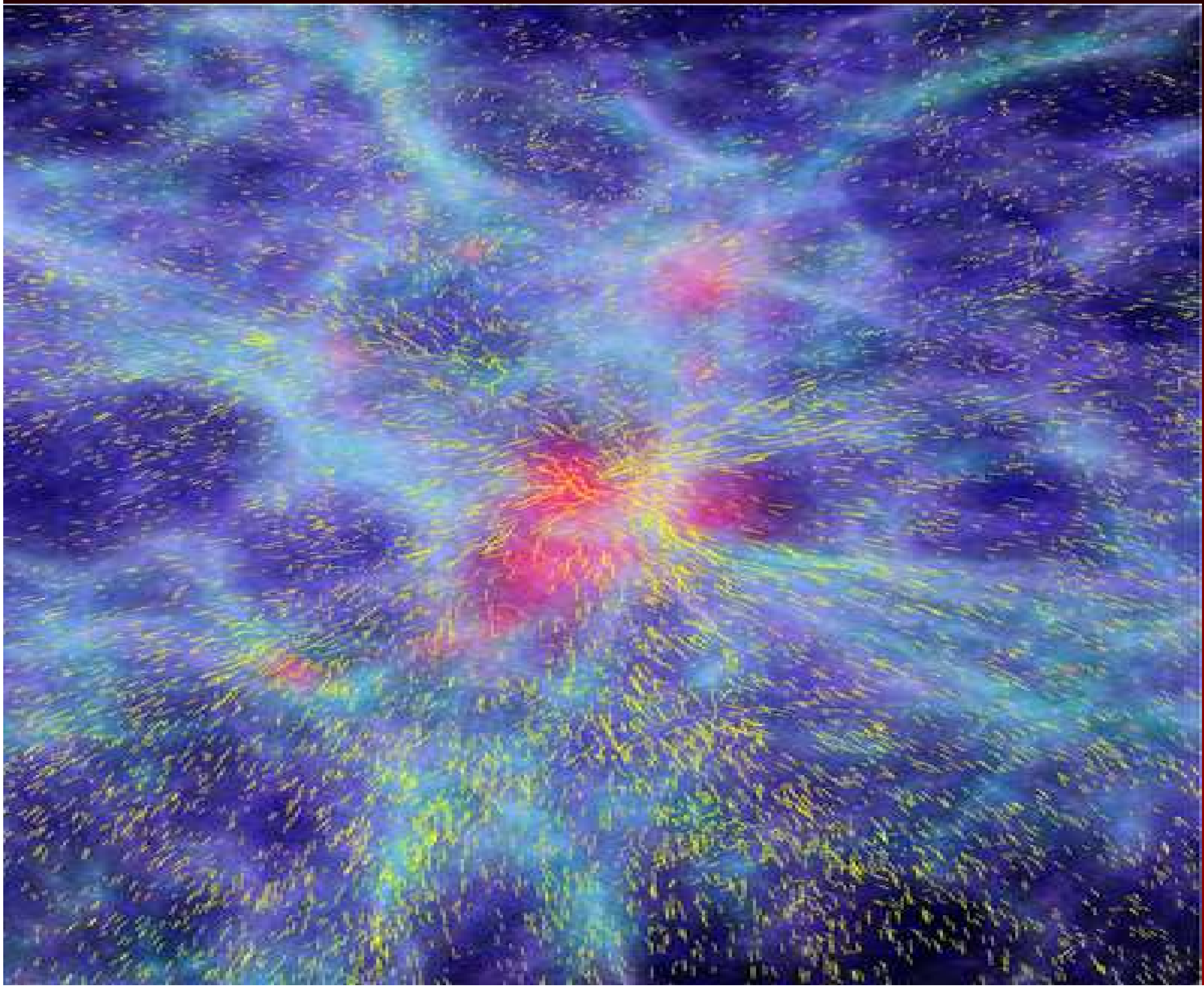
There are several observational approaches that can lead to the determination of f(z).

- Redshift distortions of galaxy clustering ($\xi(r)$, P(k))
- The rms mass fluctuation $\sigma_8(z)$ from galaxy and Ly −surveys
- Weak lensing statistics,
- Xray/Optical galaxy clusters,
- Integrated Sachs-Wolfe (ISW) effect.

Unfortunately, the currently available data are limited in number and accuracy and come mainly from the first two categories

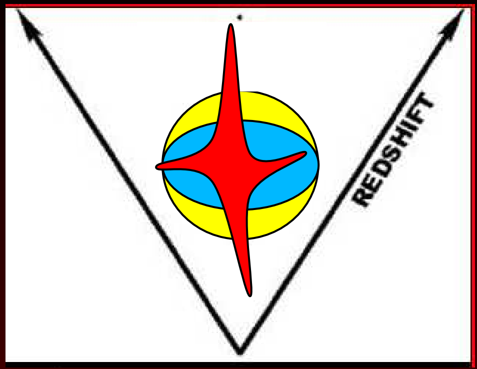
Estimating f from large scale galactic dynamics

How big a fluctuation is ? Interpret distortion signatures introduced by motions toward density maxima



Random motions increase power on small scales along the L.o.S.

Bulk motions increase power on large scales perpendicular to the L.o.S.



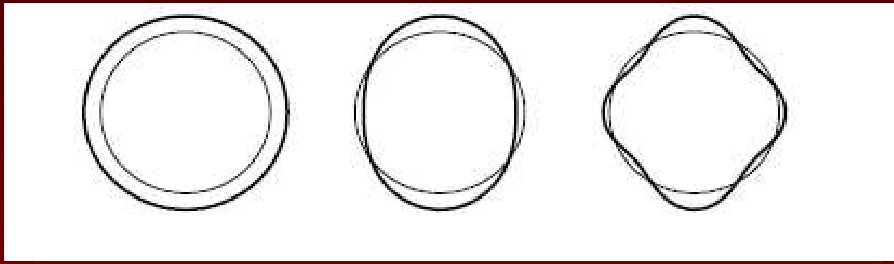
Method : Measure correlation of fluctuations in radial and transverse direction

$$\xi(\vec{r}) = < \delta(\vec{x})\delta(\vec{x}+\vec{r}) >$$

Linear Theory

$$\xi_L(r_p,\pi) = \sum_{even}^{4} a_l(s) P_l(\mu) \qquad r = \sqrt{r_p^2+\pi^2} \qquad \mu = \hat{s}\cdot\hat{\pi}$$

Legendre Polynomials



$$a_0 \propto (1+\frac{2}{3}\beta+\frac{1}{5}\beta^2)$$

$$a_2 \propto (\frac{4}{3}\beta+\frac{4}{7}\beta^2)$$

$$a_4 \propto \frac{8}{35}\beta^2$$

$$\beta = \frac{f}{b_L}$$

Hamilton 1998

Non Linear Model

$$\xi(r_p,\pi) = \int_{-\infty}^{+\infty} \xi_L\left(r_p, \pi - \frac{v(1+z)}{H(z)} \right) f(v)dv$$

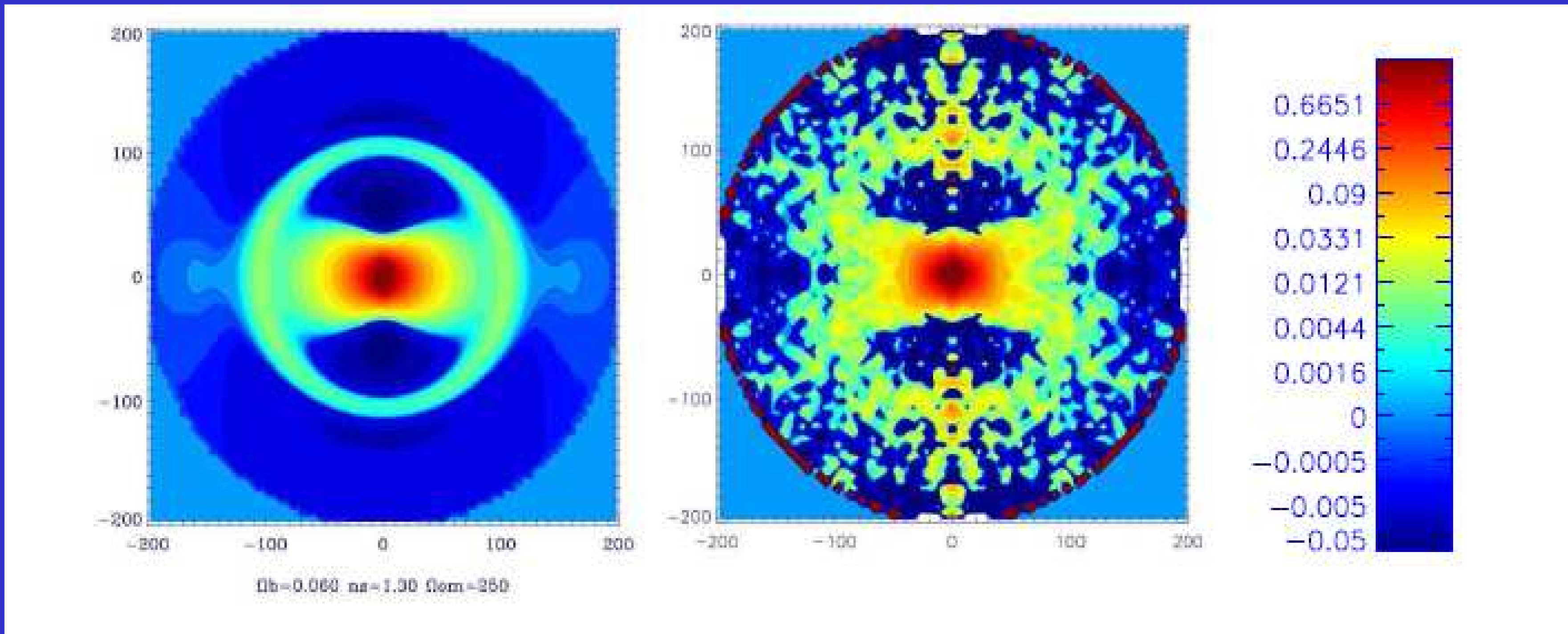
$$f(v) = \left(\sigma_{12}\sqrt{2}\right)^{-1} \exp\left(-\sqrt{2}\,|v|/\sigma_{12}\right)$$

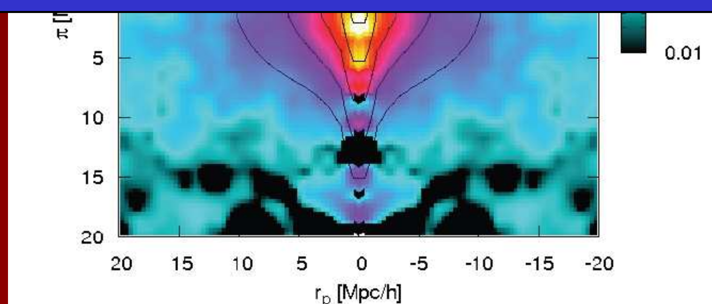
f = PDF of relative velocities of galaxy pairs

σ = describes small-scale thermal random motion

Redshift distortions in the 2 point correlation function: results

Detection of the baryonic ring





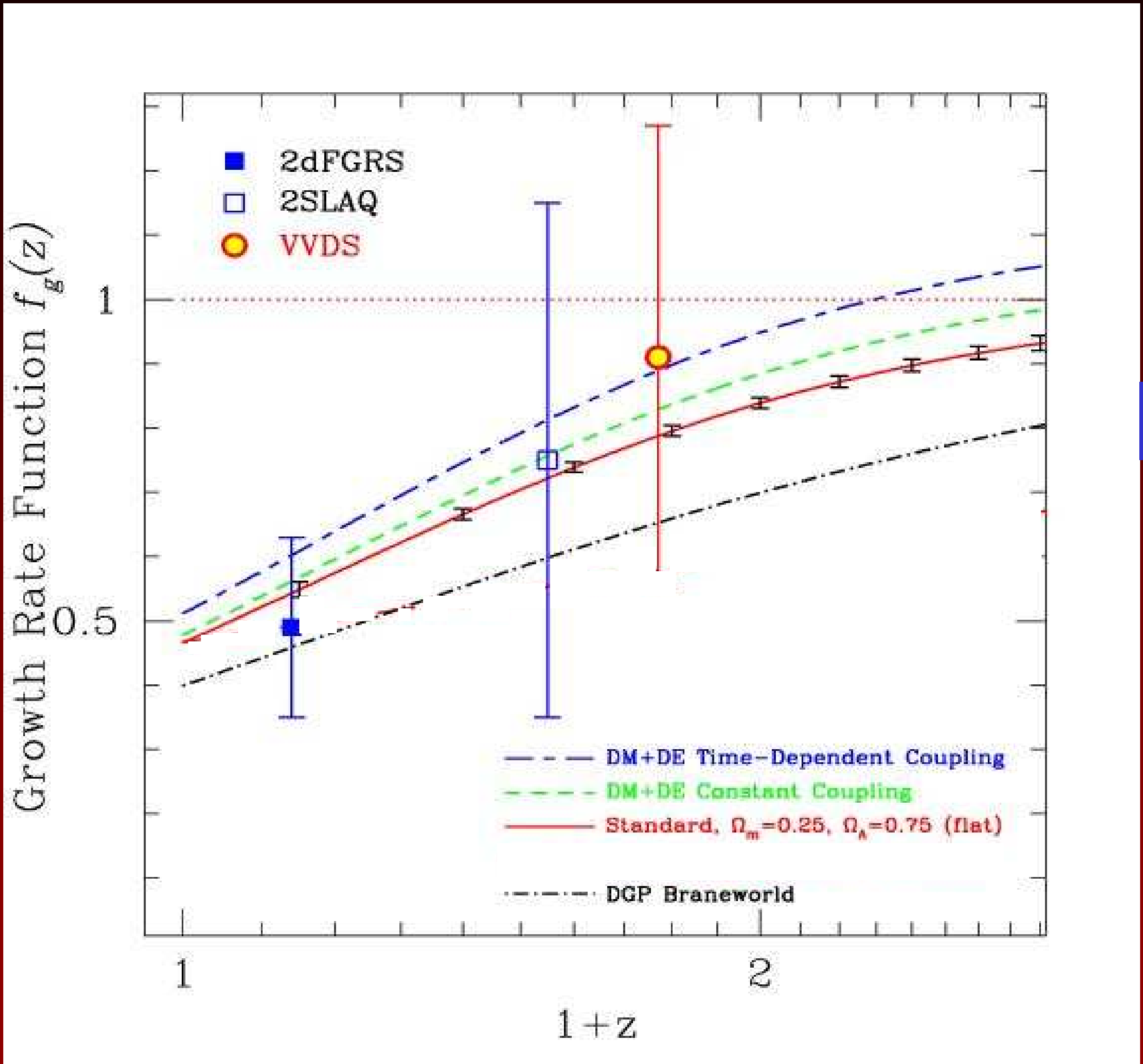
10,000 galaxies

f=0.9±0.4

σ=400±50 km/s

(Guzzo, et al. 2008 Nature)

Constraining the physics behind acceleration



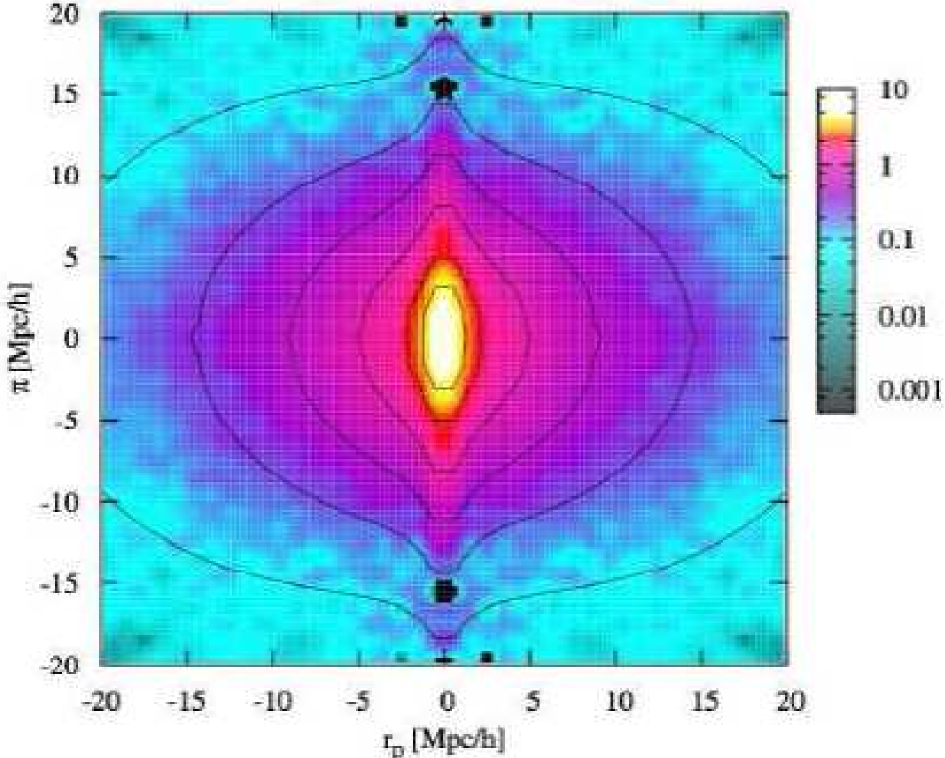
In linear theory

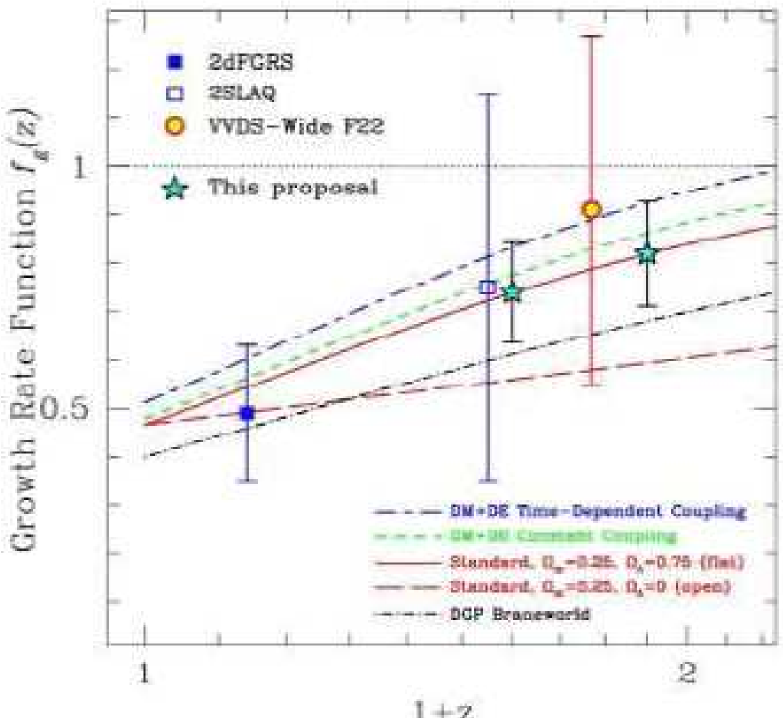
$$f(t) = \Omega_m(t)^\gamma$$

df/f(z=0.8)=45%

Low density models marginally consistent!

Next 3 years

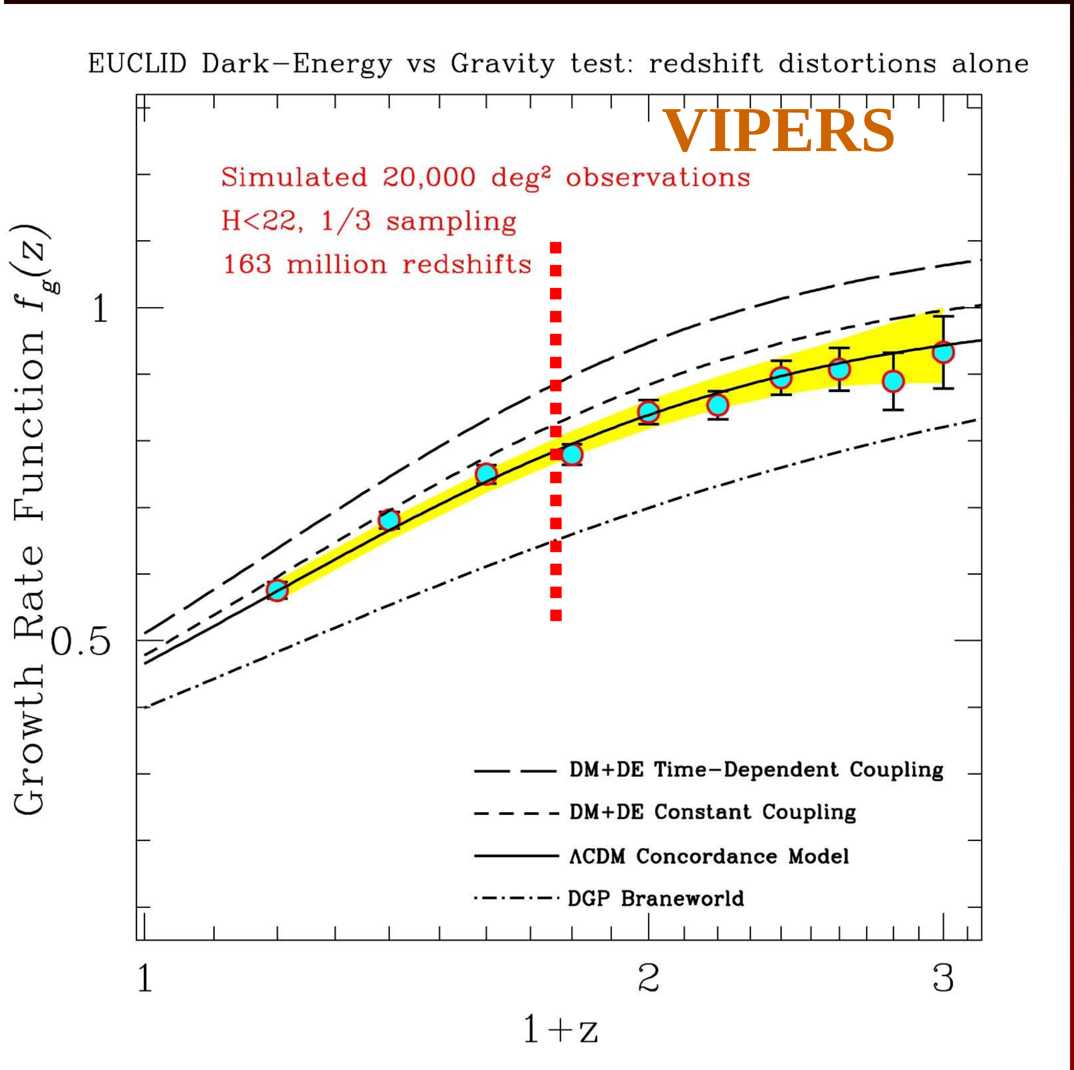




VIPERS survey (P.I. G. Guzzo)
Ω=24deg^2
I_{AB}<22.5
Sampling 1/3
100,000 redshifts

VIPERS
df/f=15%
dγ/γ=23%

Next 10 years

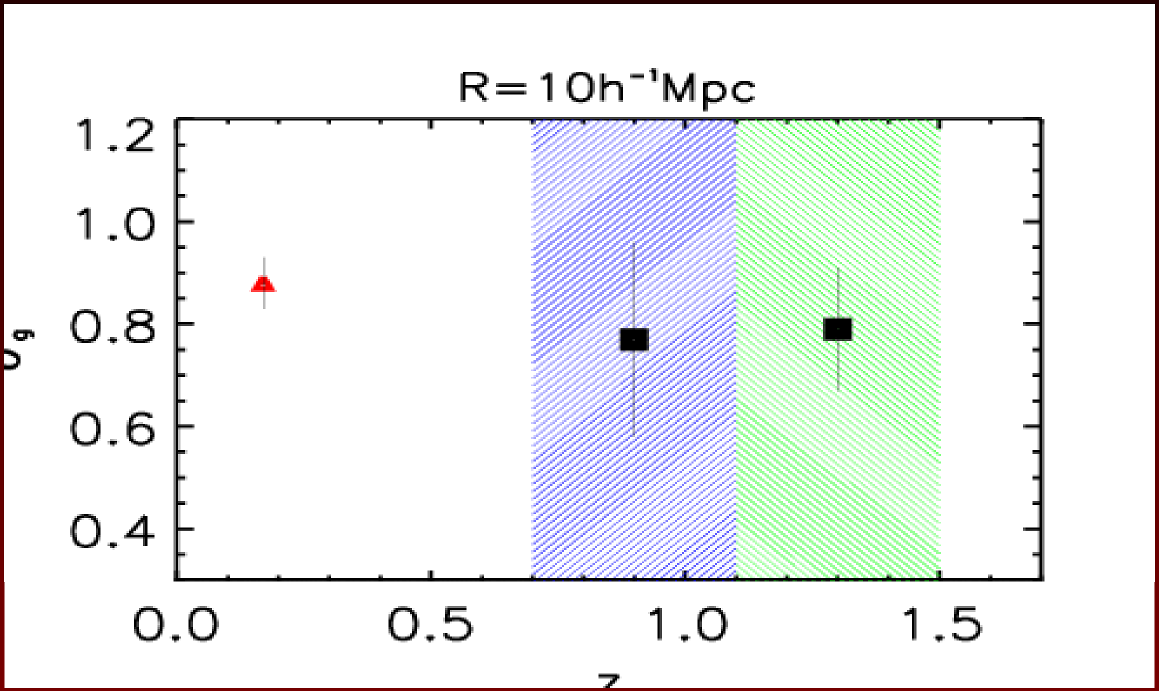


Euclide
$\Omega = 2\pi$ sr
H<22
Sampling 1/3
1.6 10^8 galaxies

....if you know the bias to 1%

Euclide
df/f=1%
dγ/γ=1.5%

Testing the consistency of the Gravitational Instability Paradigm (a statistical approach)



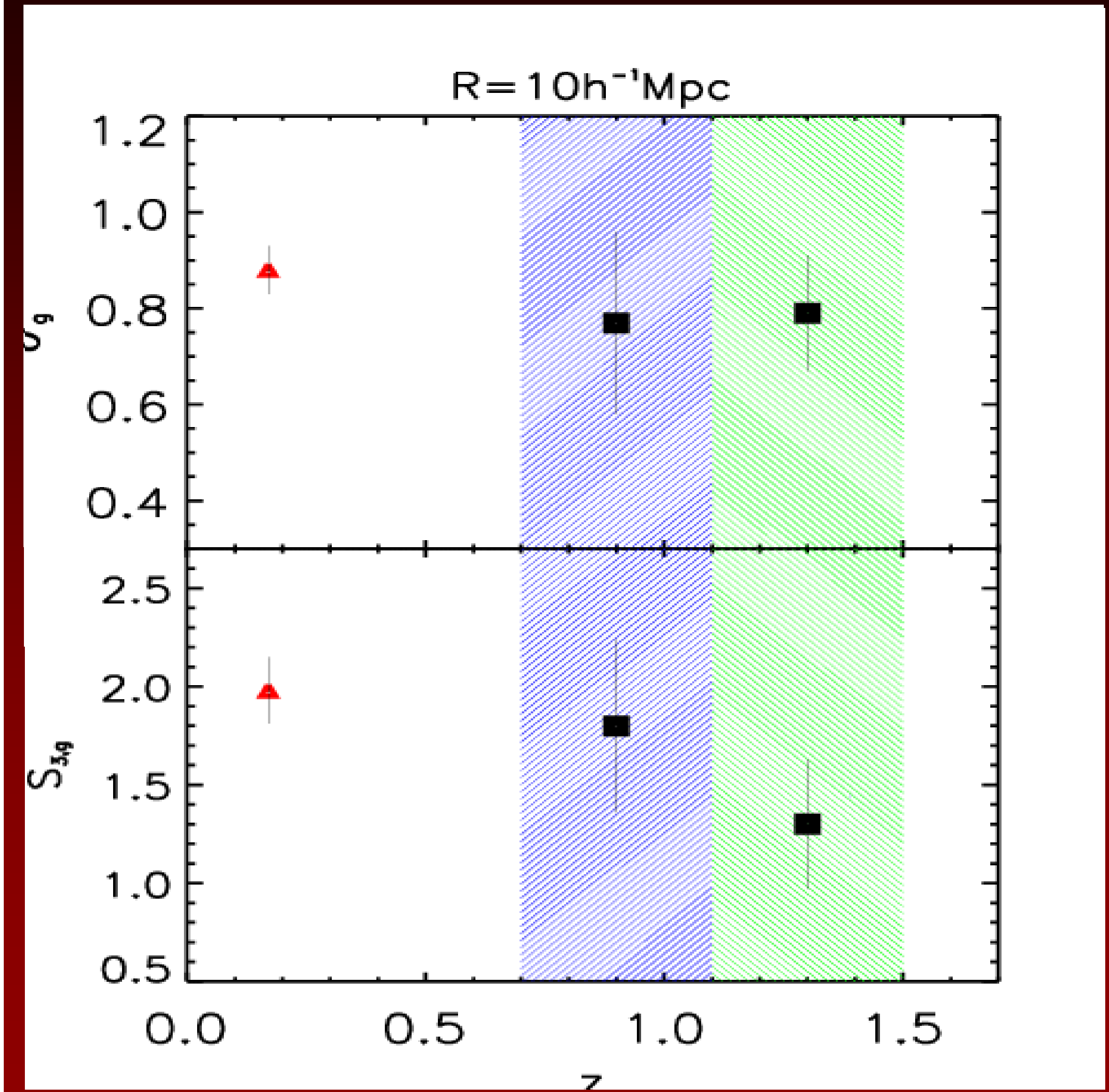
Marinoni et al. A&A 2008 (arXiv:0802.1838)

Second Moment

Fluctuations in the visible sector have frozen over ~2/3 of the history of the universe

The Young universe was as much inhomogeneous as it is today

Testing the consistency of the Gravitational Instability Paradigm
(a statistical approach)



Marinoni et al. A&A 2008 (arXiv:0802.1838)

Second Moment

Fluctuations in the visible sector have frozen over ~2/3 of the history of the universe

The Young universe was as much inhomogeneous as it is today

Third Moment

Galaxy distribution was significantly non Gaussian even at early times

Testing gravity with third order statistics : Skewness

$$\left\langle \delta^3(x,t) \right\rangle \sim \left\langle \delta^{(1)}(x,t)^3 \right\rangle + 3\left\langle \delta^{(1)}(x,t)^2 \delta^{(2)}(x,t) \right\rangle + ...$$

$$S_3 = \frac{\left\langle \delta^3(x,t) \right\rangle}{\left\langle \delta^{(1)}(x,t)^2 \right\rangle^2} = 6\iint F_2(\vec{k}_1, \vec{k}_2) d\Omega_1 d\Omega_2$$

Gaussian linear density field + Standard gravity

$$S_3(z) = \frac{34}{7} + \frac{d \ln \sigma_R^2}{d \ln R} + \frac{6}{7}\left(\Omega_0^{-1/140} - 1\right)$$

Juszkievicz et al. 1993

Galaxy skewness

$$S_{3,g}(z) = b_1^{-1}\left[S_3 + 3\frac{b_2}{b_1} \right]$$

Fry & Gaztanaga 1993

Redshift distortions

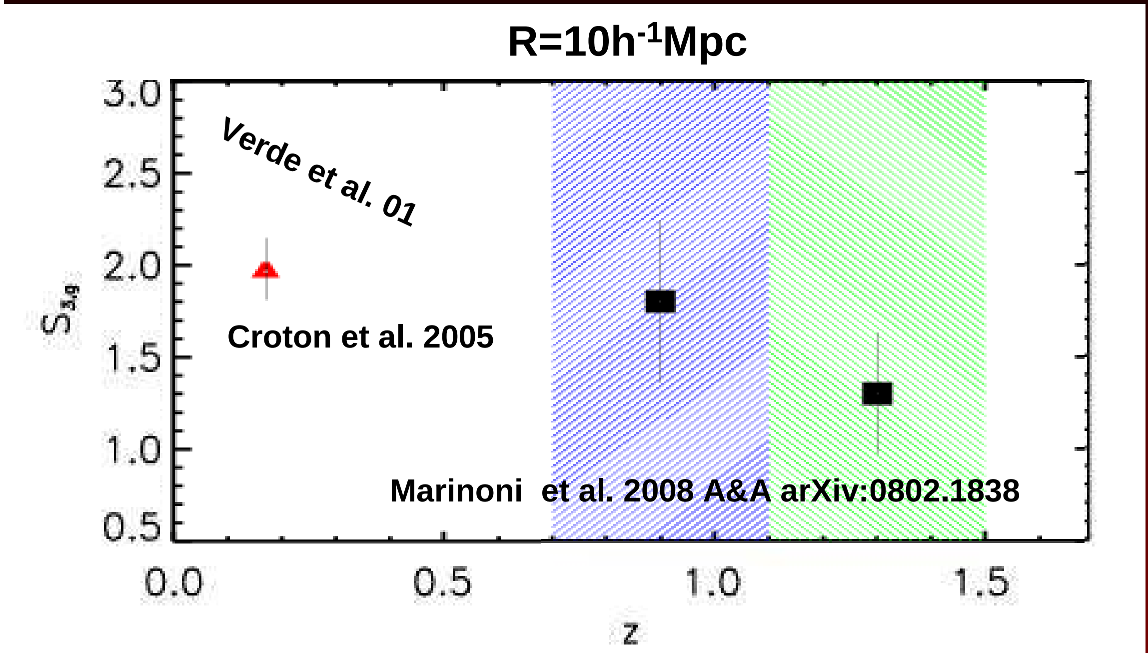
$$S_3(z) = \frac{35.2}{7} - 1.15(n+3)$$

Hivon 1995

Biasing reconstruction

$$\delta_g = \sum_k \frac{b_k}{k!} \delta^k \qquad \left\langle \frac{b_2}{b_1} \right\rangle = -0.19 \pm 0.04$$

Testing gravity with third order statistics : Skewness



Mass skewness

$$S_3(z) = \frac{34}{7} + \frac{d\ln\sigma_R^2}{d\ln R} + \frac{6}{7}\left(\Omega_0^{-1/140} - 1\right)$$

Juszkievicz et al. 1993

Galaxy skewness

$$S_{3,g}(z) = b_1^{-1}\left[S_3 + 3\frac{b_2}{b_1}\right]$$

Biasing reconstruction

$$\delta_g = \sum_k \frac{b_k}{k!}\delta^k \qquad \left\langle \frac{b_2}{b_1} \right\rangle = -0.19 \pm 0.04$$

Conclusions:

Local biasing is non-linear at the level we predict at high z

→ ΛCDM predictions are consistent with data over 9Gyrs

Local biaising is linear as often assumed in literature

→ One need to question gravity/gaussianity …… (or local measurements!)

What is causing the accelerated expansion of the Universe?

(A. Buzzi, CM, S. Colafrancesco 2008 JCAP

Assume only matter

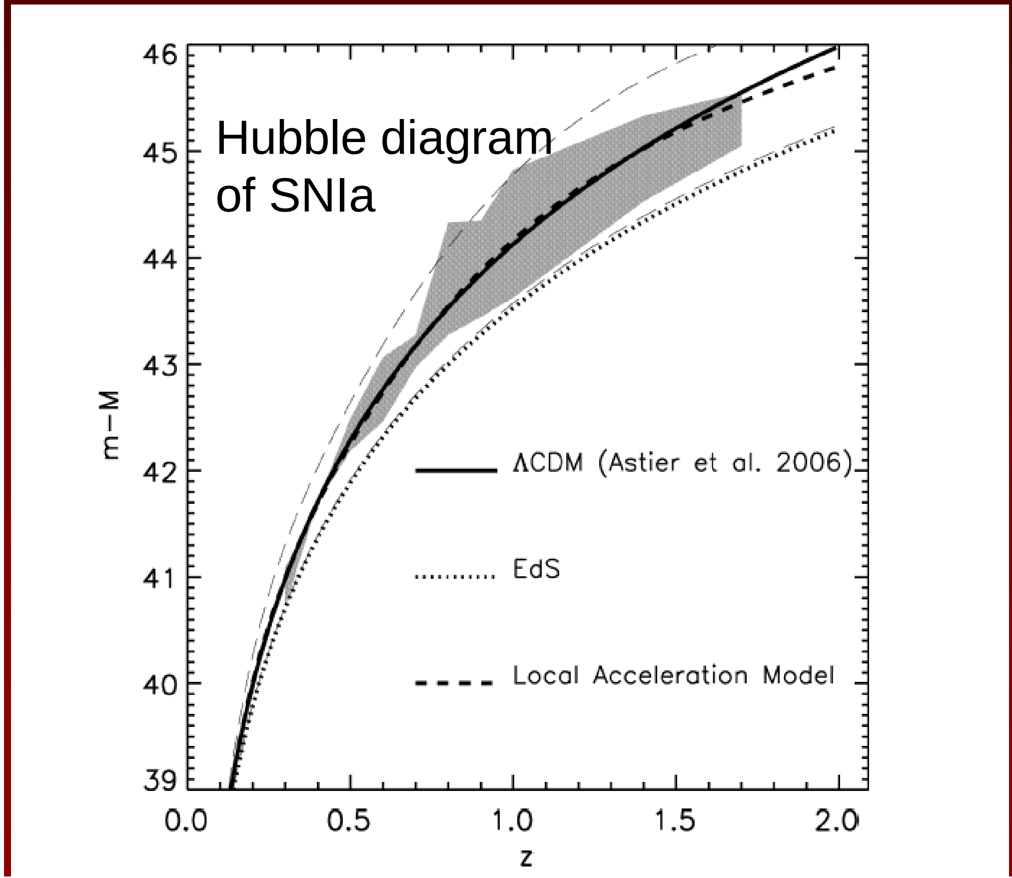
$$d_L = (1+z^o)\int_0^{z^o} \frac{c}{H(z)} dz$$

Work out the expession of $d_L(z)$ for a general « Dark Force » scenario.

$$z^o = z + (1+z)\frac{v_p(z)}{c}$$

$$\frac{dv_p}{dt} + H(t)v_p(t) = \gamma_p(t)$$

$$\gamma_p = \sum_{i=0}^{n} \gamma_i t^i(z)$$



A general non metric model can reproduce the Standard ΛCDM d_L, without violating known exprimental limits or physical principles!

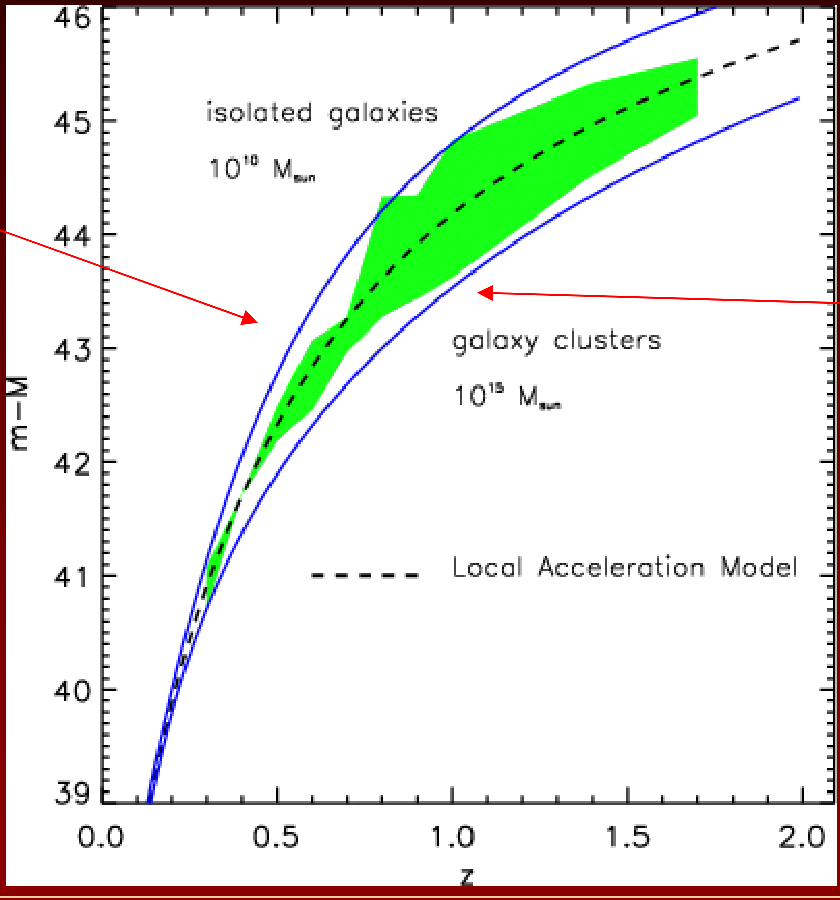
Predictions

There is a signature common to all the non gravitational acceleration mechanisms : acceleration depends on the mass of the system

→ physical interpretation of the scatter in the Hubble diagram

Less massive hosts

$10^{10}{}_{sun}$



More massive hosts

$10^{15}{}_{sun}$

Test the nature of the acceleration by performing an environnemental analysis of SNIa

Outline

- ***Testing Gravity at z=1***

  - ***with 2nd order statistics :***

    - ***redshift evolution of the linear growth factor of density fluctuations***

  - ***with 3rd order statistics :***

    - ***Redshift evolution of the skewness of the galaxy density fluctuations***

- ***Testing cosmological models***

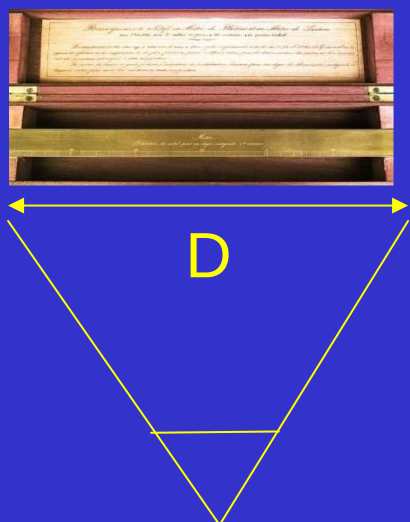
  - ***The cosmological lensing of galaxy diameters***

  - ***Counts of deep optical clusters VVDS+DEEP2***

Metric constraints using the kinematics of high redshift disc galaxies

Marinoni, Saintonge, Giovanelli et al. 2008 A&A , 478, 41
Saintonge, Master, Marinoni et al. 2008 A&A, 478, 57
Marinoni, Saintonge Contini et al. 2008 A&A , 478, 71

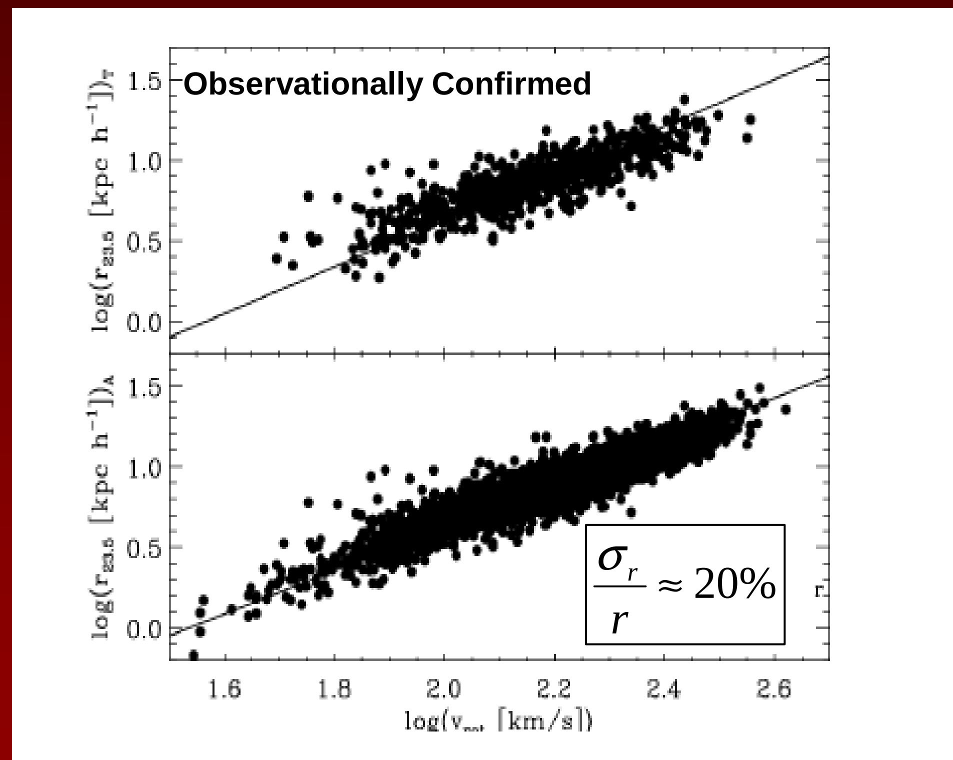
Angular Diameter Test



$$\theta(z) = \frac{D}{d_A(z,\Omega)}$$

Standard Rod Selection

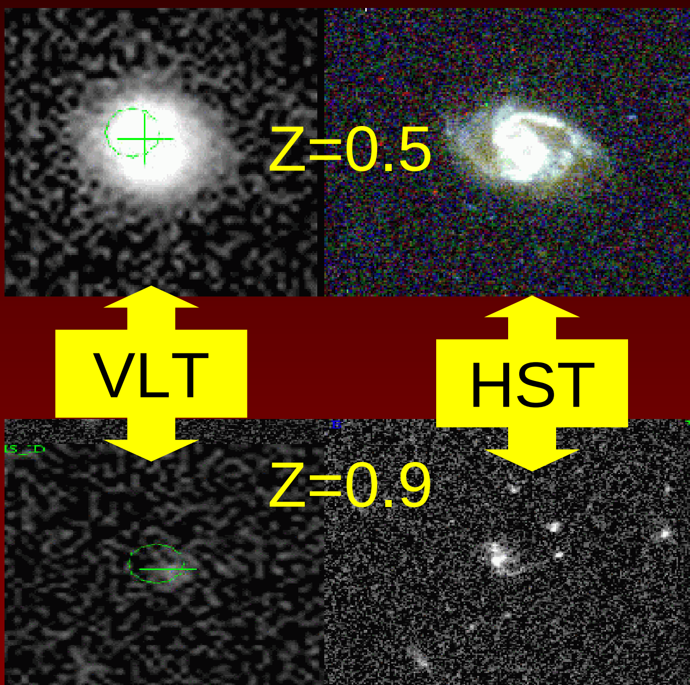
Theory predicts : $D \propto V^{\alpha}$



Saintonge, Master, Marinoni et al. 2008 A&A,478, 57

Implementation Strategy:

HST/Cosmos imaging survey:



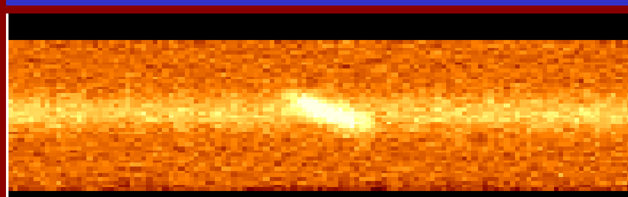
Observations underway with VIMOS at VLT in the COSMOS field
(accepted ESO proposal 2009, P.I. L. Tresse)

Very Quick (…but large) Survey!!

~1300 rotators down to Iab 22.5 in only 30h

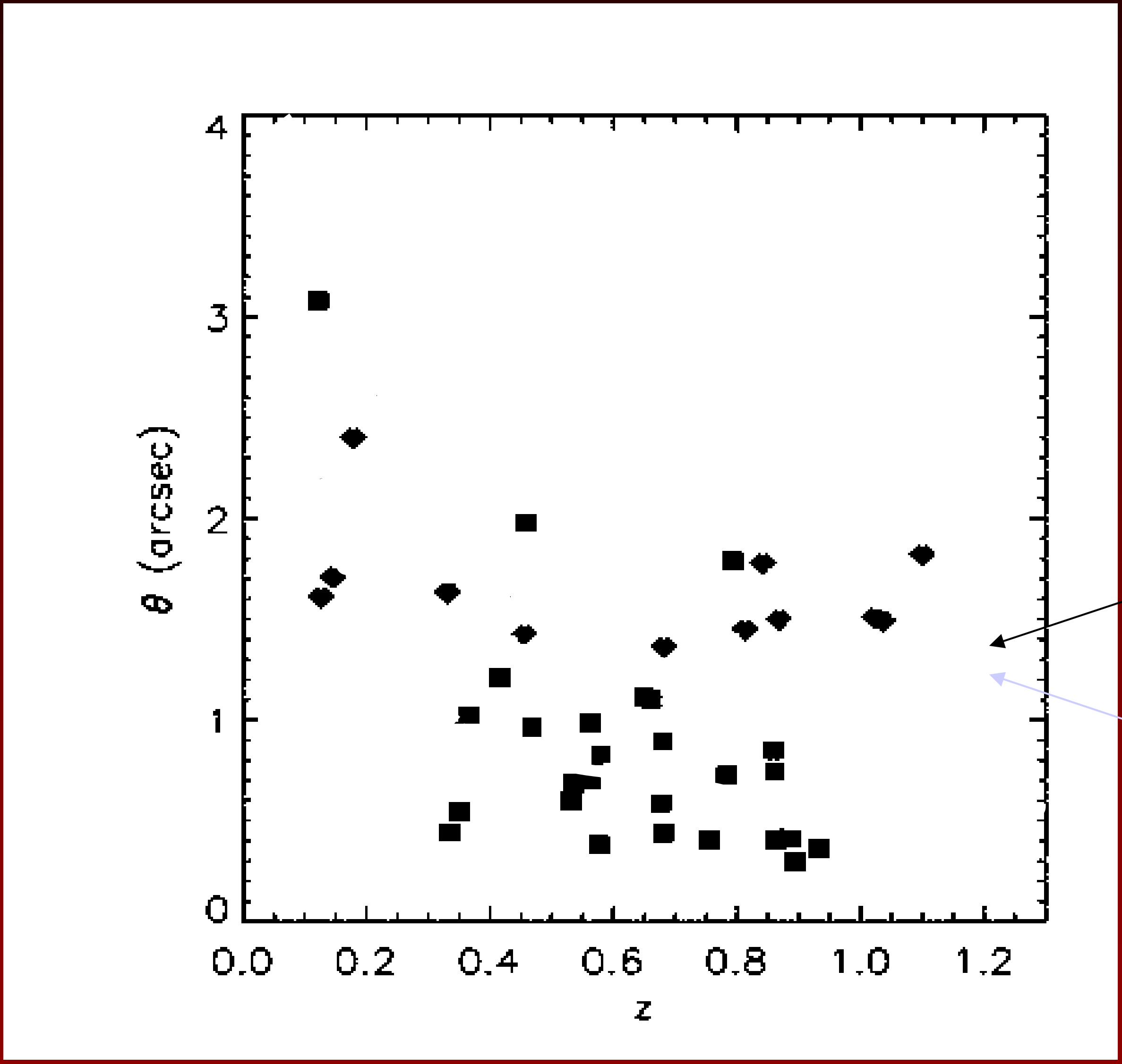
Retarget in High spectroscopic resolution zCOSMOS discs with known emission lines and redshift

HR Spectroscopy (VIMOS)



Preliminary data

Standard Rod Selection



Comparison with the predicted angular evolution in the standard ΛCDM background

$$\Omega_m = 0.25,\ \Omega_X = 0.75,\ \ w = -1$$

Best fitting model

ΛCDM

Test of the Cosmological Principle

Many cosmological tests make use of only two functions of redshift

The angular diameter distance $d_A(z)$ and the radial comoving distance r(z)

These two quantities are not independent, as they are related by the cosmic consistency relation (e.g. Stebbins 2007)

$$d_A(z) = \frac{1}{K} S_k \left[K \; r(z) \right]$$

where

$$S_k[x] = x, \sin(x), \sinh(x) \quad \text{for} \quad k = 0, +1, -1$$

$$K = |1 - \Omega_0|^{-1/2} \frac{c}{H_0}$$ Spatial curvature

Violation of consistency might indicate Non-RW geometry

Why Galaxy Clusters?

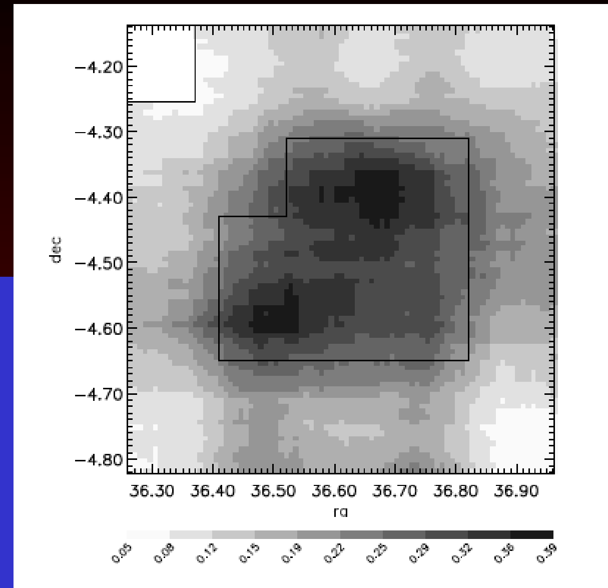
“The panel concluded that the evolution of cluster abundances as a function of mass had in principle higher potential than SN and BAO. Not only in constraining cosmological parameters, but also because the combination of growth and distance tests can provide a fundamental test of GR.”

DETF panel

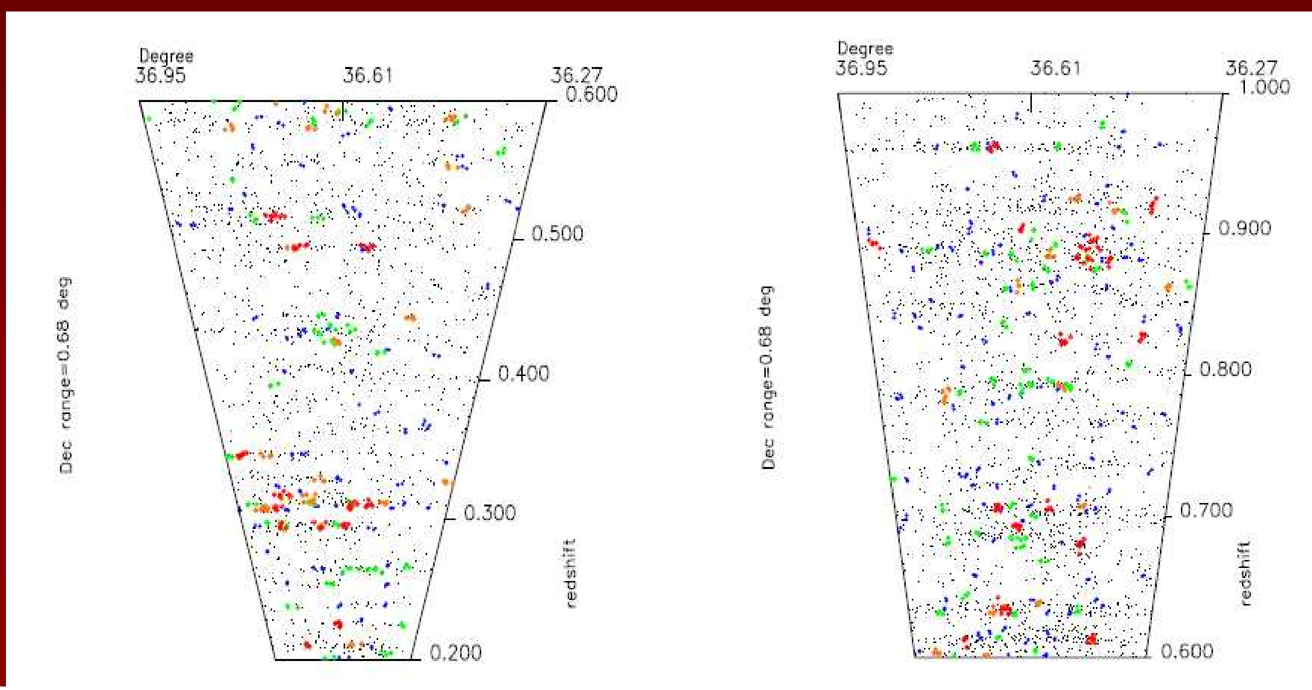
Theoretical issues : understanding of the mass-observable relation. And it is not yet clear how well this will be able to be done.

Observational issue : identifying and reconstructing virialized systems in cosmological surveys?

The VVDS 02 (deep) field

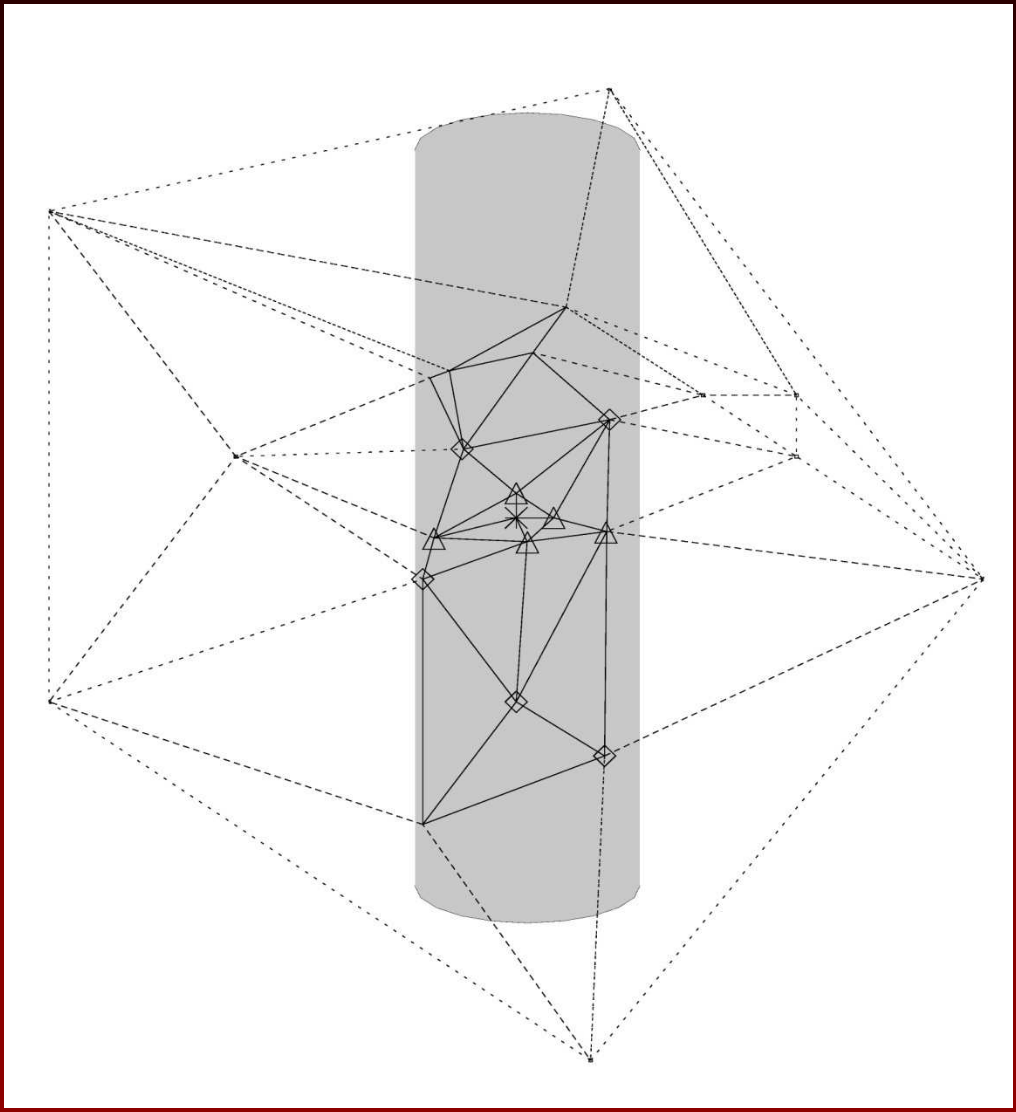


- Number of redshifts 6615
- Redshift range 0.2<z<1.5
- Sky area 0.7×0.7 deg2,
- Depth I=24
- Average Sampling 18% (33% considering only the area covered by 4 passes).
- Volume V=1.5 × 10^6 h^{-3} Mpc^3



Reconstructing clusters in deep spectroscopic surveys

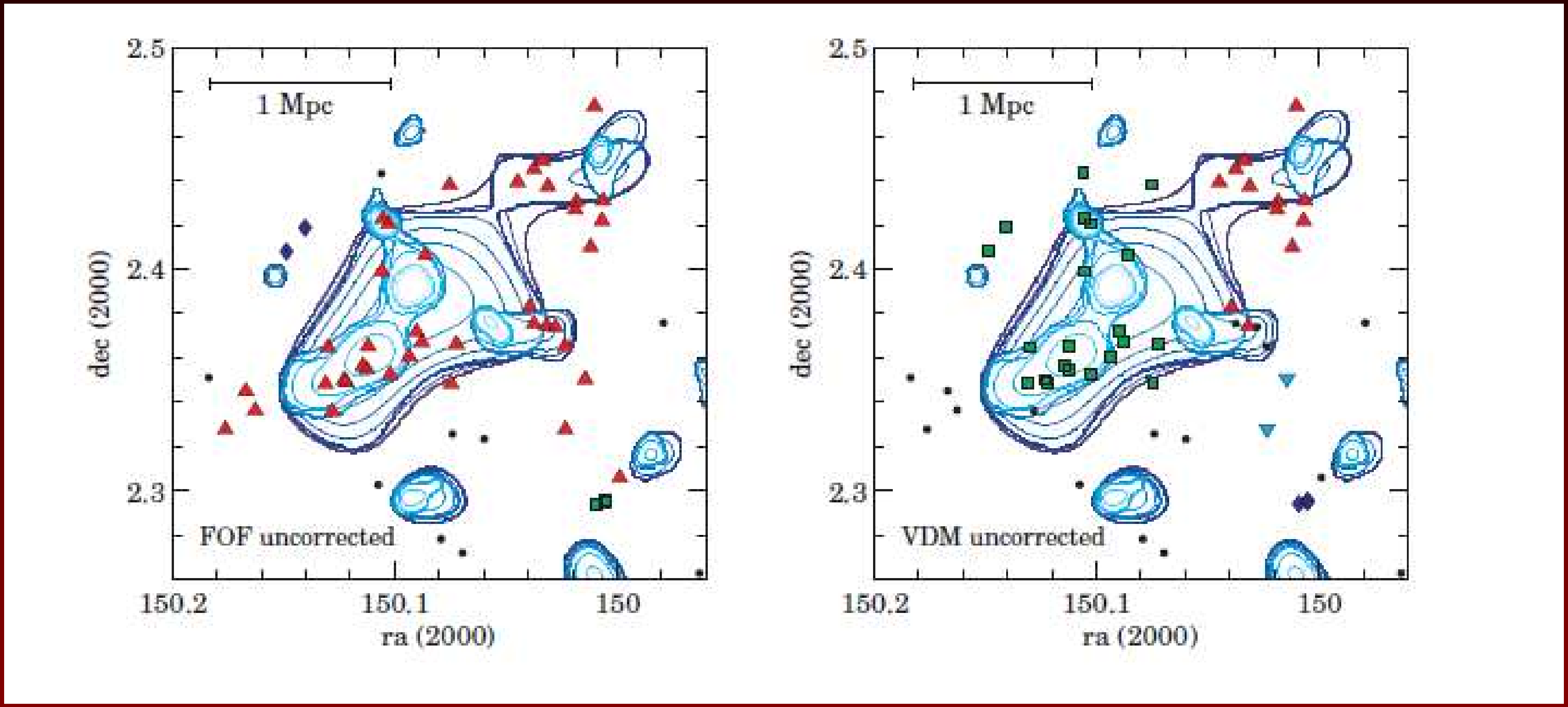
3D Voronoi-Delaunay Method (VDM)



$$\Sigma_0 \propto r^{\alpha}$$

Marinoni, Davis, Newman & Coil 2002

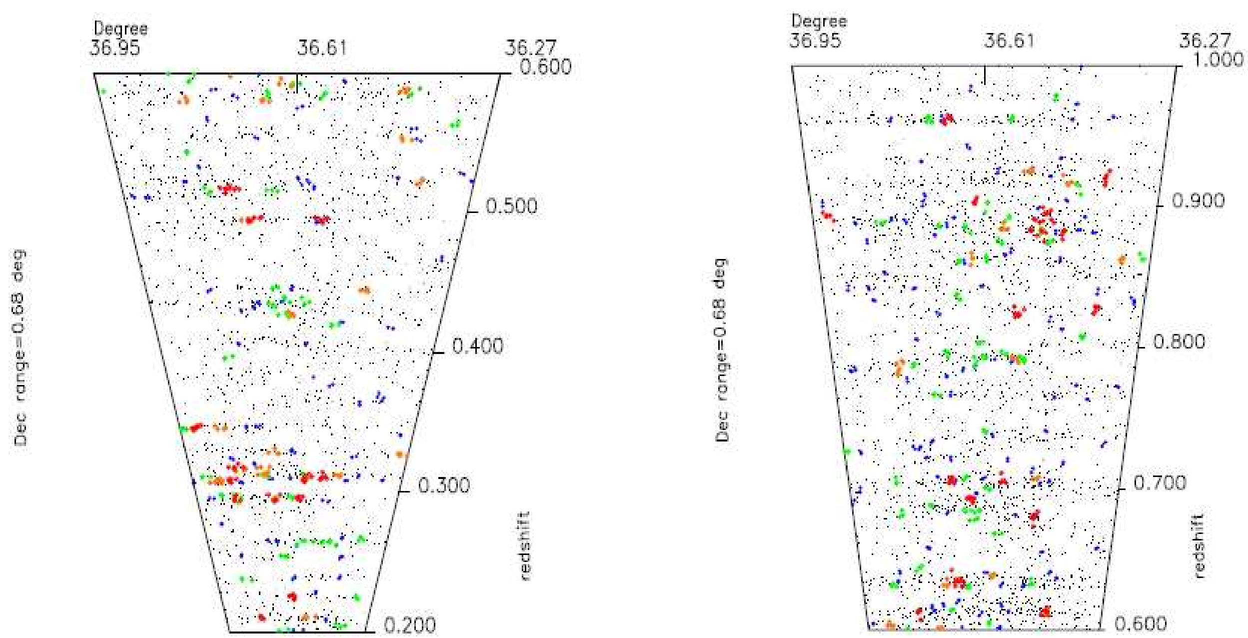
(FOF) (VDM)



Knoebel et al. 2009

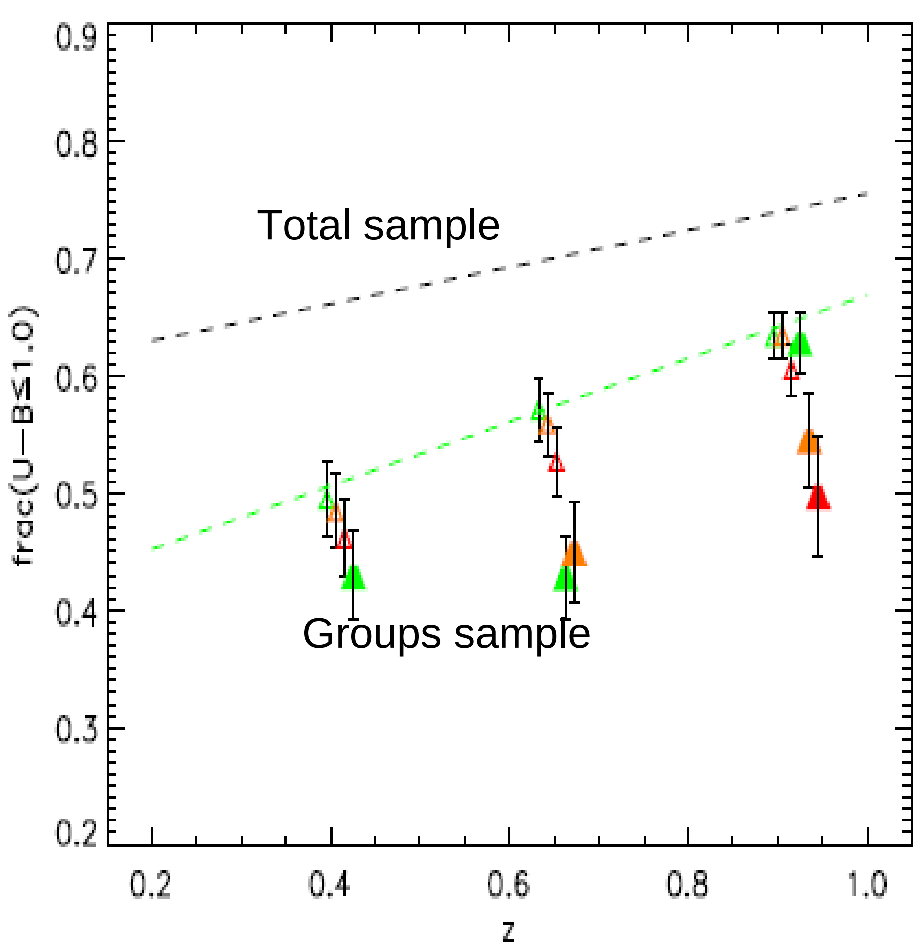
The VVDS-02 Group Sample

σ (km/s)	Group members								
	2	3	4	5	6	7	8	9	ALL
$\sigma = 0$	89(23)	24(10)	8(2)	-	-	-	-	-	121(35)
$0 < \sigma < 350$	61(25)	39(18)	18(6)	8(5)	3(2)	3(3)	2(1)	-	134(60)
$\sigma \geq 350$	24(-)	19(6)	6(3)	5(1)	4(2)	3(2)	1(-)	1(1)	63(15)
								Total:	318(110)



Environmental studies

Blue Fraction as a function of redshift



Blue galaxies : U-B<1 at all redshifts

Galaxy Cluster Abundance

Dependence on cosmological parameters

of clusters per unit redshift:

$$\boxed{\frac{dN}{dz}} = \frac{dV}{dz} \times \int_{M_{\min}}^{\infty} dM \, \frac{dn}{dM}$$

comoving volume — mass limit — mass function

mass function:

$$\frac{dn}{dM} = \frac{1}{(2\pi)^{1/2}} \frac{\bar{\rho}}{M} \left(\frac{\delta_c}{\sigma_M} \frac{d \ln \sigma_M}{dM} \right) e^{-\frac{\delta_c^2}{2\sigma_M^2}}$$

P&S formula

overall normalization $(\propto \Omega_M h^2)$

power spectrum (σ_8, n)

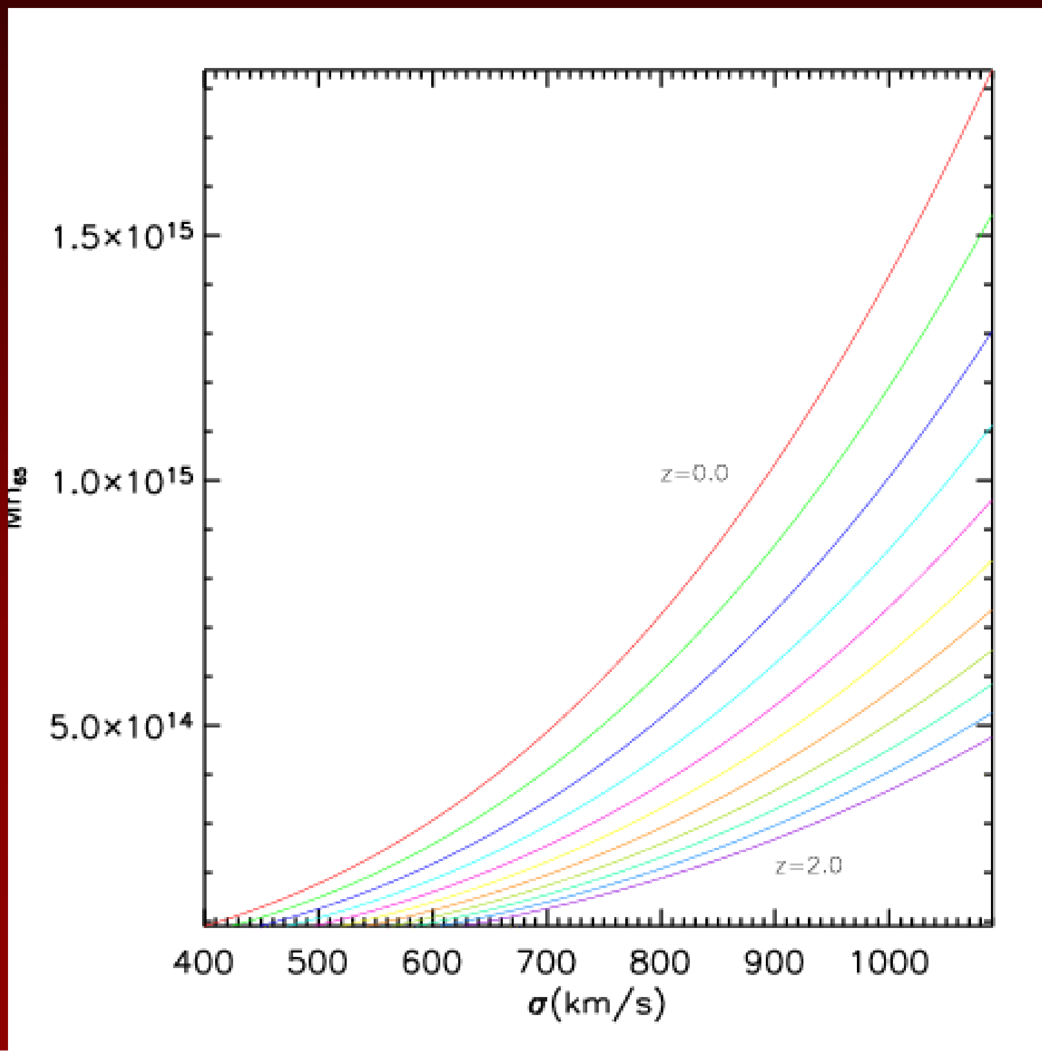
growth function (Ω_m, Ω_X, w)

Velocity Function Evolution

Mass is not an observable!

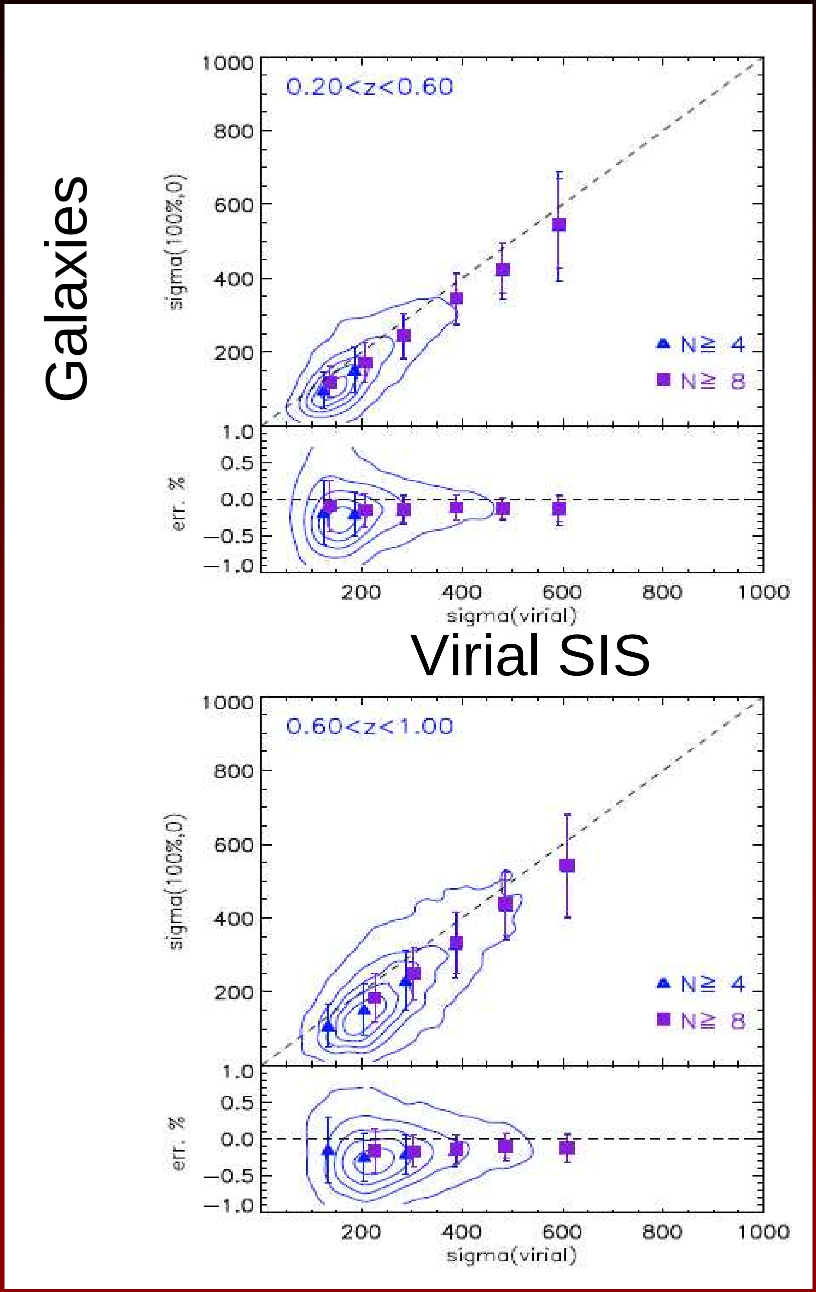
→ Use velocity dispersion

$$\frac{d^2N}{dz\,d\sigma} = \frac{dn}{dM}\frac{dV}{dz}\frac{dM}{d\sigma}$$



A given M corresponds to increasing σ at higher redshift

The best we could do…in principle



Real Space
Velocity-Velocity calibration

VVDS Mock catalogs
(Millennium Simulation)

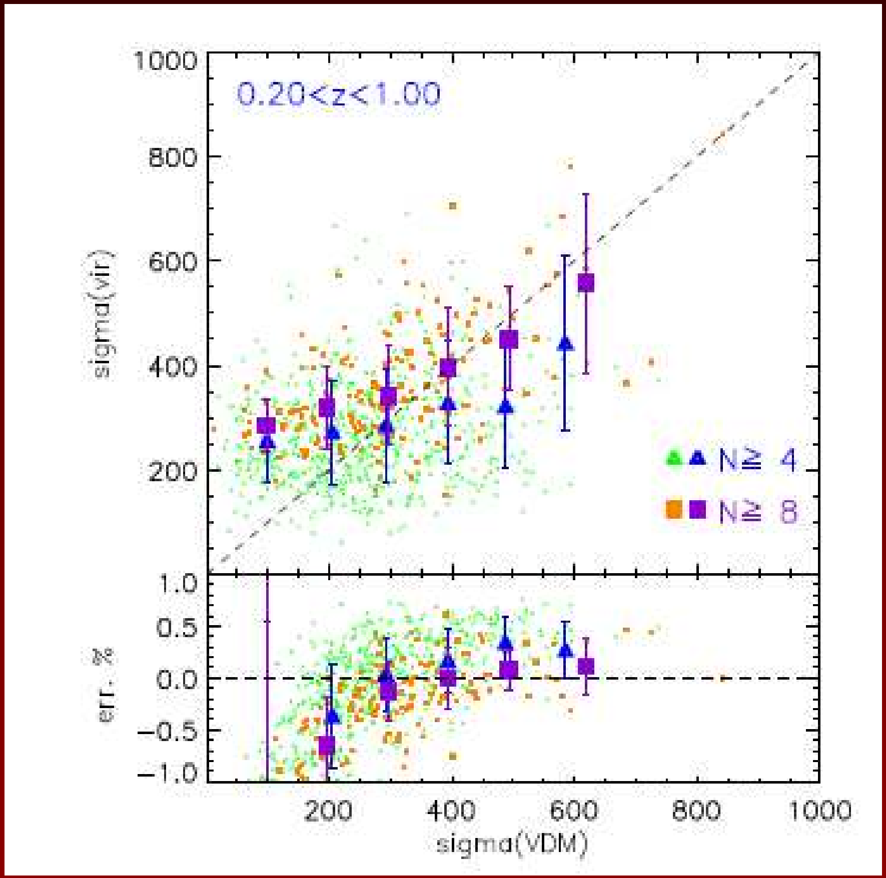
σ-σ relation calibrated to 8%

(Cucciati, Marinoni Iovino et al. 2009 A&A submitted)

The best we can actually do

Redshift Space Performances

VVDS Mock catalogs + VDM algorithm



V>350km/s threshold

Cucciati, Marinoni, Iovino et al. 2009 A&A submitted

Mass is not an observable!
Use velocity dispersion

Newman, Marinoni & Davis 2003

$$\frac{d^2N}{dz\,d\sigma} = n(M)\frac{dV}{dz}\frac{dM}{d\sigma}$$

Velocity Function Evolution

Theoretical Issues

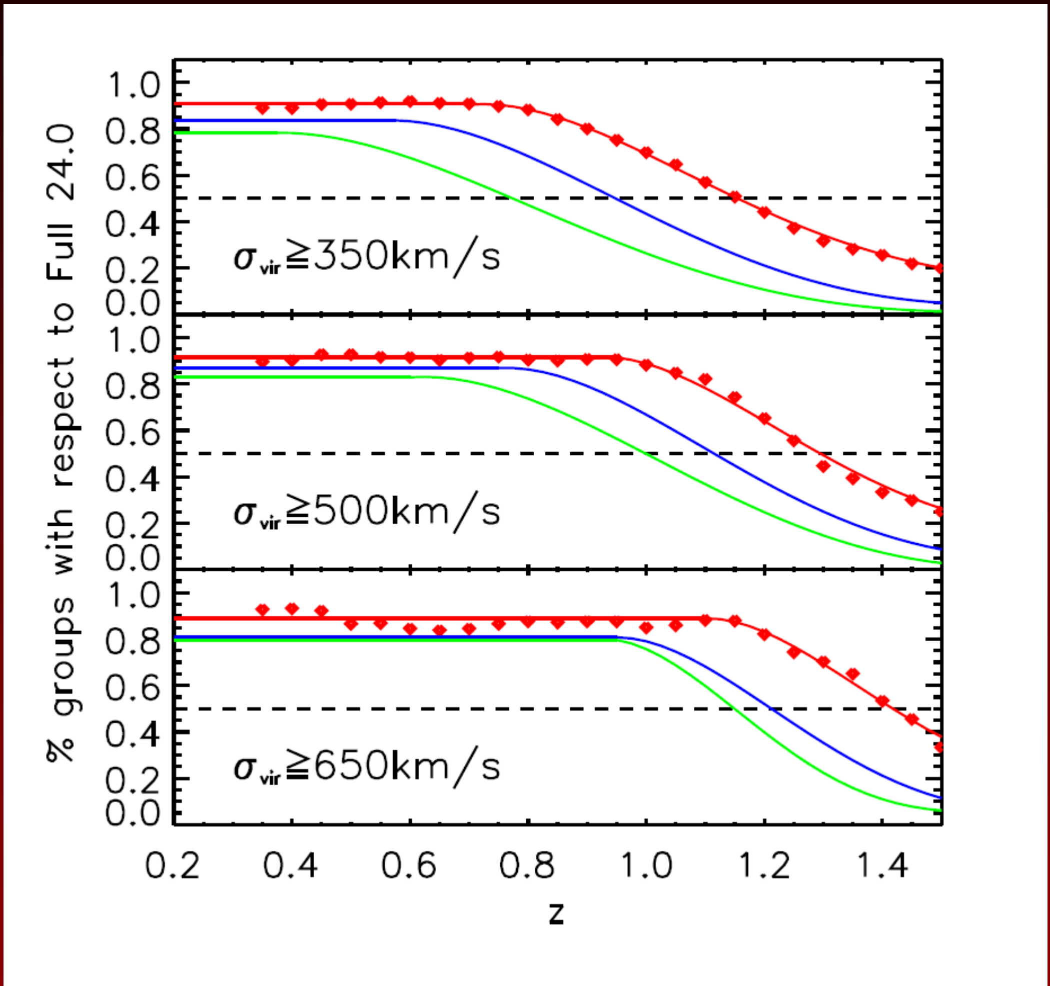
- **What is a Cluster ? Spherically collapsed isothermal sphere**

  Need to check velocity-velocity calibration with simulation

Observational Issues

Selection functions determination N(z|σ), N(σ|z)

N(z) completeness



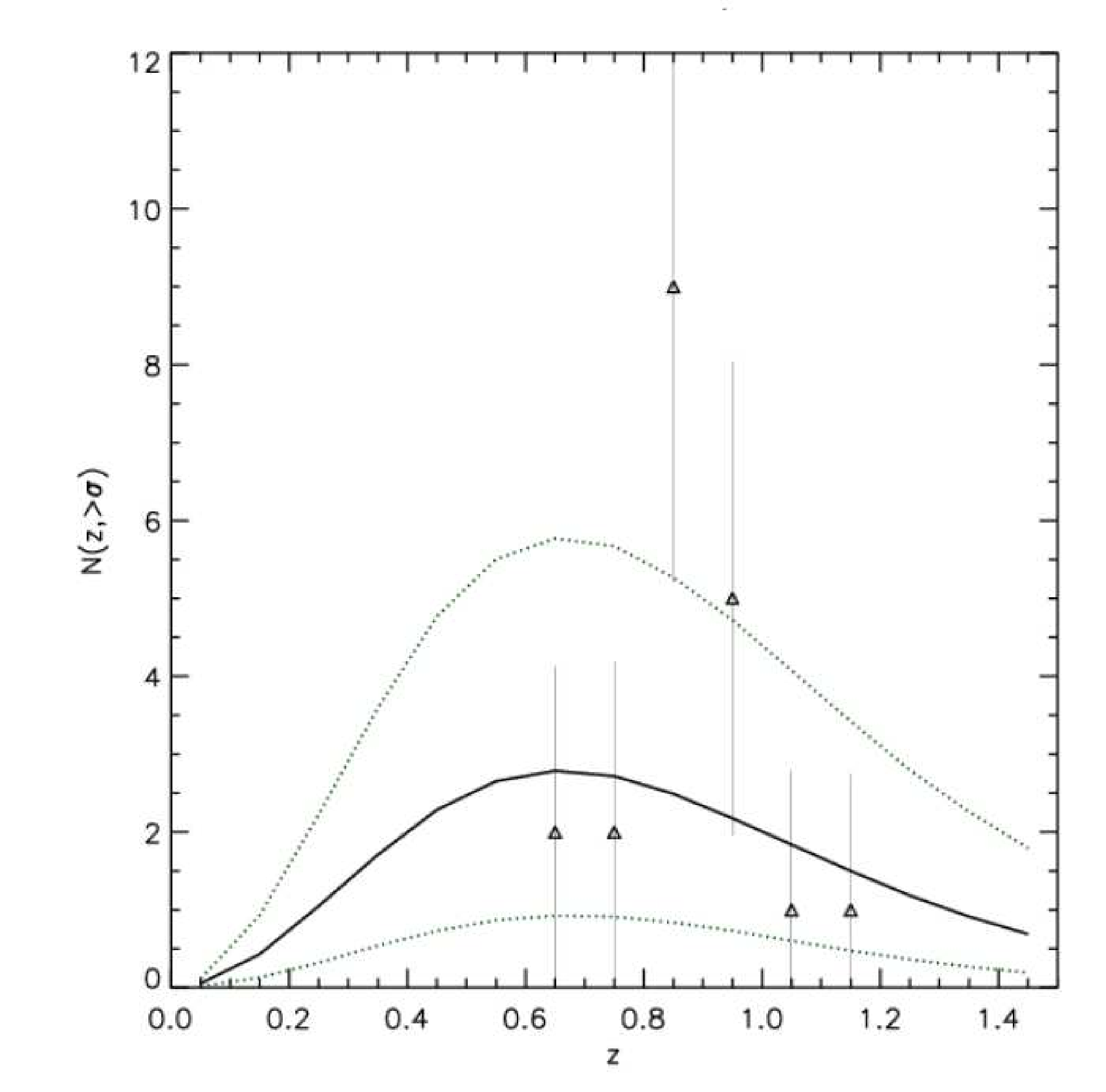
(Cucciati, Marinoni, Iovino et al. 2009 A&A submitted)

Average over 20 VVDS-like mock catalogs (extracted from the Millennium simulation)

$$\psi(z \mid \sigma, f_{VVDS}, I_{VVDS})$$

The σ>500km/s group sample is complete up to z=1.

Preliminary Results : VVDS + Deep2 Cluster Counts



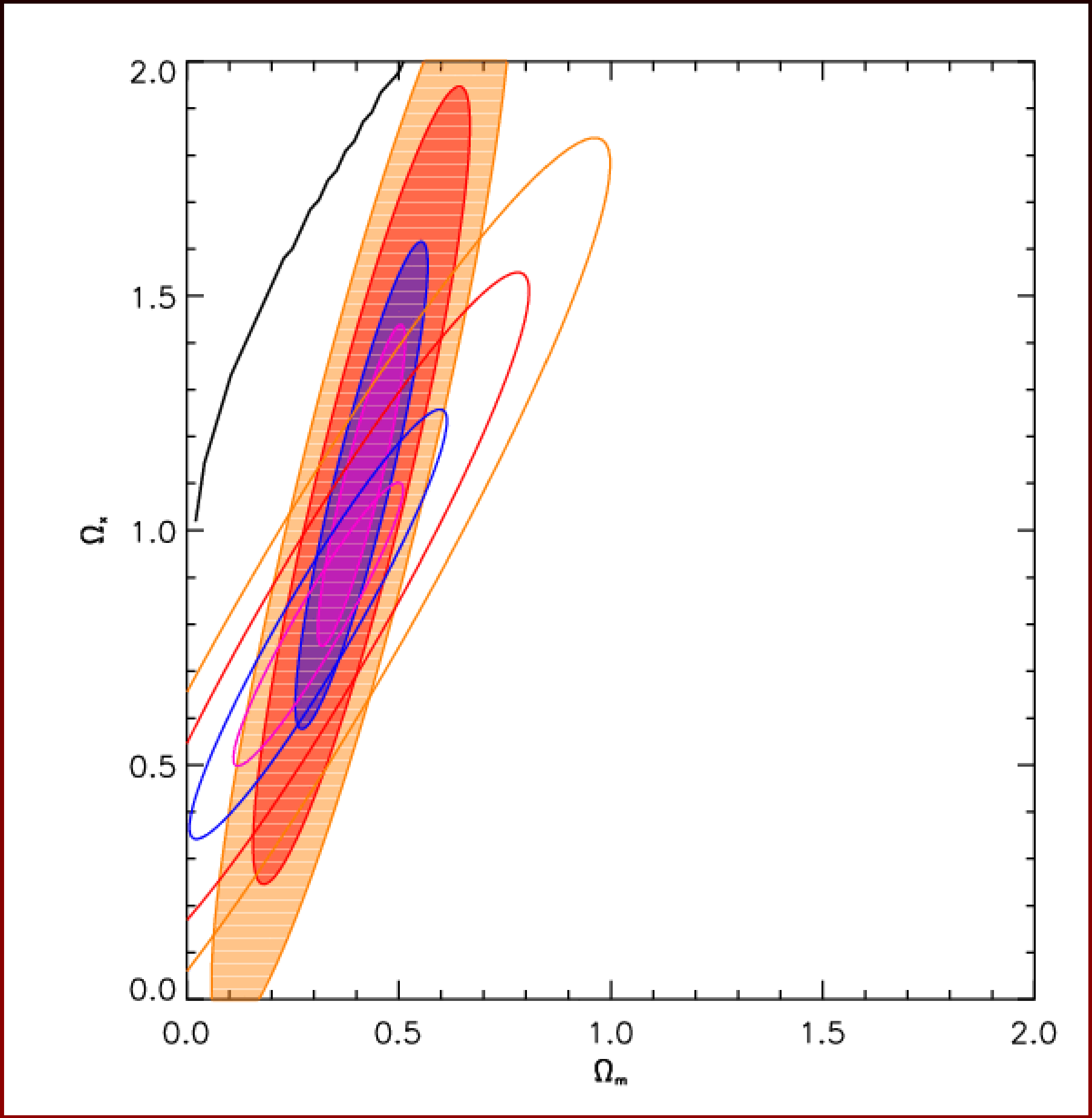
Area
1.47 deg^2

Redshift range:
$0.6<z<1.2$

Error Budget
Poisson + sys

Velocity Threshold
$\sigma_{los} = 600 km/s$

Cosmological Constraints from DEEP2+VVDS



Area

1.47 deg^2

Redshift range:

0.6<z<1.2

Error Budget

Poisson + sys

Velocity Threshold

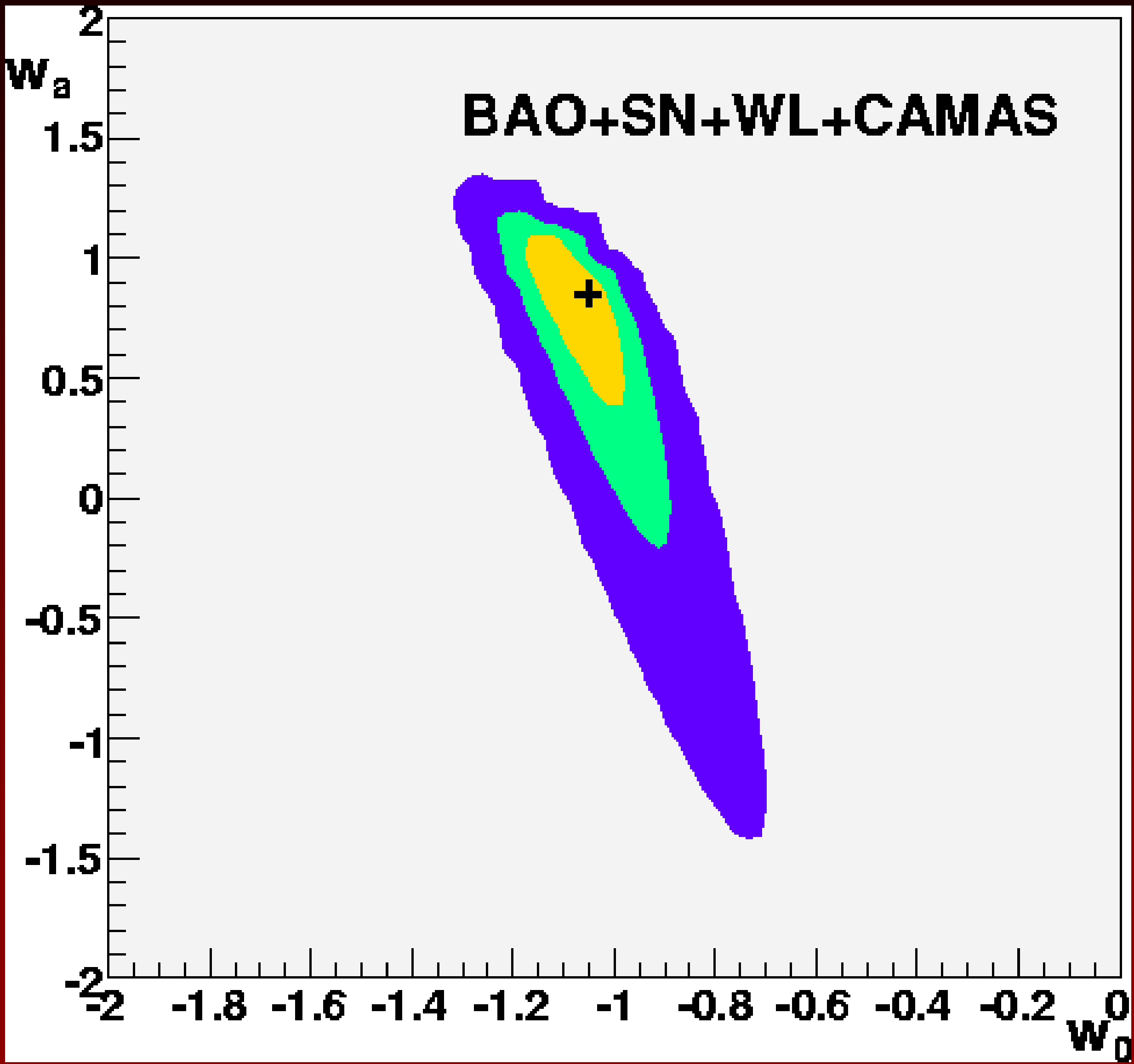
$\sigma_{los} = 600 km/s$

Priors

- P(k) slope $n = 0.96 \pm 0.015$
- P(k) normalisation $\sigma_8 = 0.76 \pm 0.036$

Virey, Marinoni et al. 2009 in prep.

Joint Likelihood



Virey, Marinoni et al. 2009 in prep.

Conclusions

-Evolution of the linear growth factor gives insigths into the nature of DE. Still large errorbars affects VVDS measurements.
Need larger deep surveys (e.g. SPACE/Euclide)

Right now : VIPER (P.I. L. Guzzo)
24 sq. deg. N=100,000 galaxies, I<22.5

Conclusions

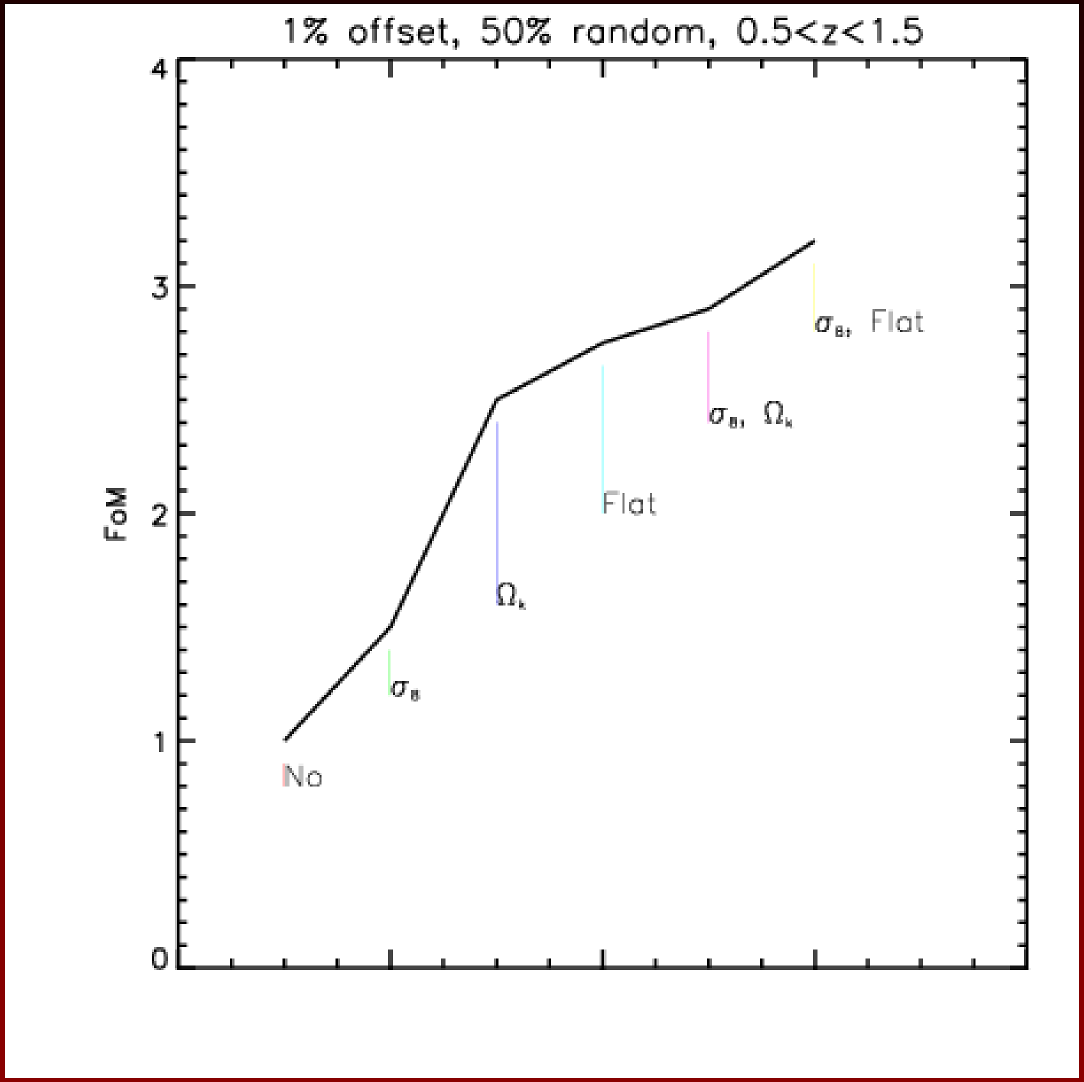
-Evolution of the linear growth factor gives insigths into the nature of DE. Still large errorbars affects VVDS measurements. Need larger deep surveys (e.g. SPACE/Euclide)

- semi-linear GIP predictions for skewness evolution are consistent with data in the range $0<z<1.5$ only if biasing is <u>non-linear</u> at the level measured by VVDS. If local ($z=0$) bias is linear → GIP ruled out at 5 sigma by current data

- Observations underway in the COSMOS/HST field to collect a large sample of velocity selected standard rods (VIMOS @ VLT) and test cosmology with the angular diameter test of cosmology

- Optical Clusters are a unique tool to constrain DE via their velocity function evolution. Preliminary results from VVDS+DEEP2 analysis

Sensitivity to priors



- Optical clusters are a unique tool to constrain DE via their velocity function evolution.

- Preliminary results from VVDS+DEEP2 analysis extremely encouraging.

- 10000 sq.deg survey in the range $0.5<z<1.5$ and reasonable calibration uncertainties

→ FoM ~ 0.6 (Alone)

→ FoM ~ 60 (Cluster+SNIa)

- Killing factor is not σ-σ calibration, neither spectral resolution R, but sampling. Need to simulate the survey.

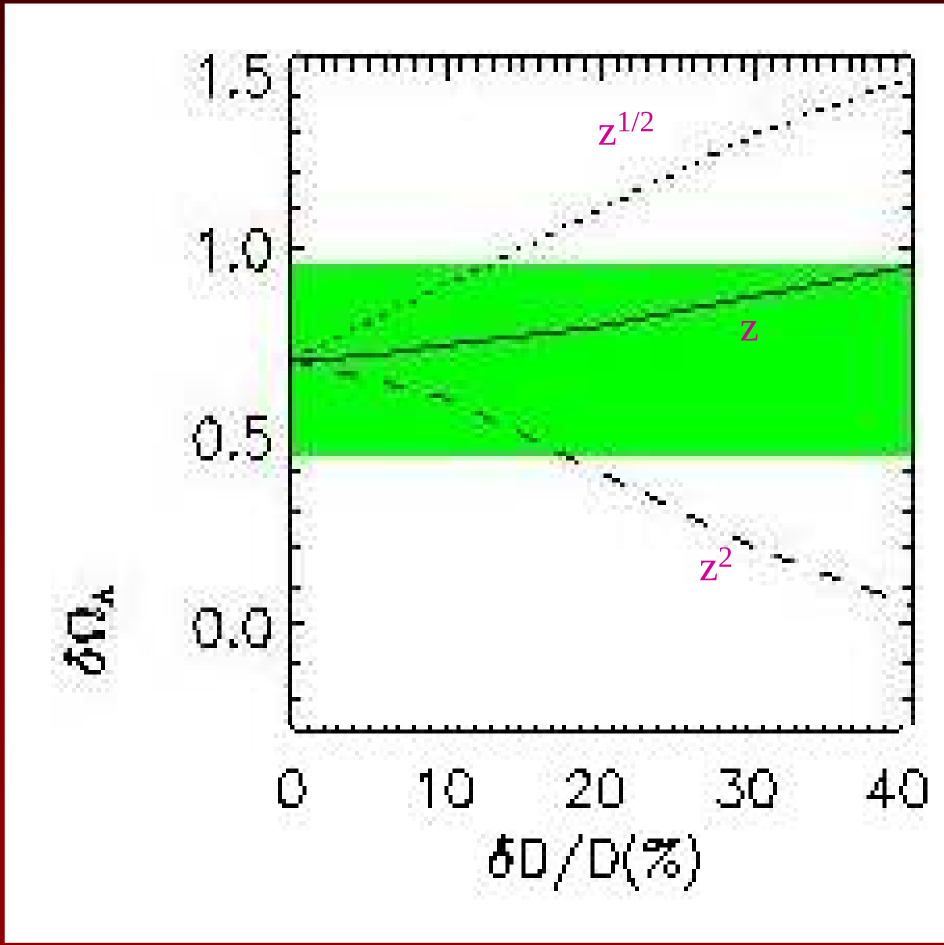
- Need explore sensitivity to gravity

Does evolution bias results?

Suppose there is a mild evolution in disc sizes

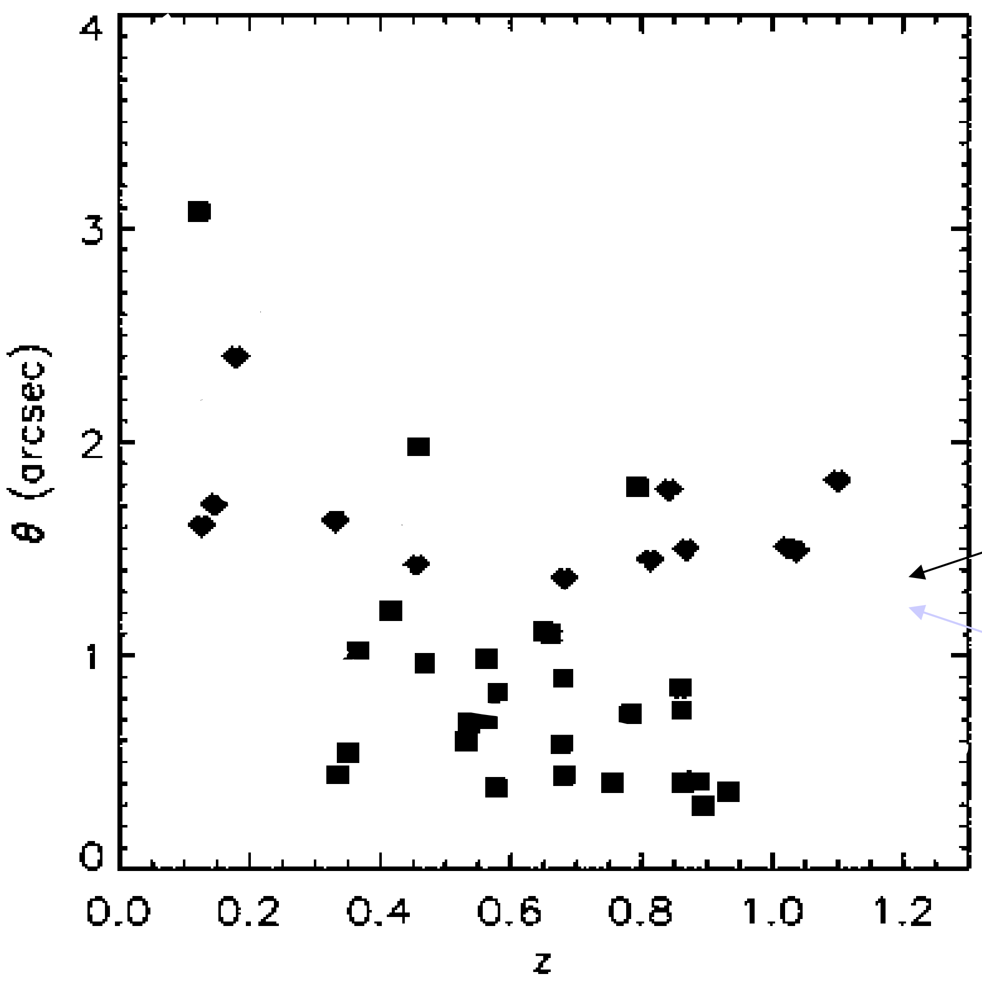
$$D(z) = D(0) + D^{'}(0)z$$

DE equation of state parameterization



Preliminary data

Standard Rod Selection



Comparison with the predicted angular evolution in the standard ΛCDM background

$$\Omega_m = 0.25,\ \Omega_X = 0.75,\quad w = -1$$

Best fitting model

ΛCDM

The PDF of mass: $\psi(\delta)$

Real Space Model Cole & Jones 1991

$$\psi(y) = \frac{1}{\sqrt{2\pi\omega^2}} \frac{1}{y} Exp\{-\frac{[\ln y + \omega^2/2]^2}{2\omega^2}\}$$

$$y = 1 + \delta \qquad \omega^2 = \ln[1 + \sigma_r(R,z)^2]$$

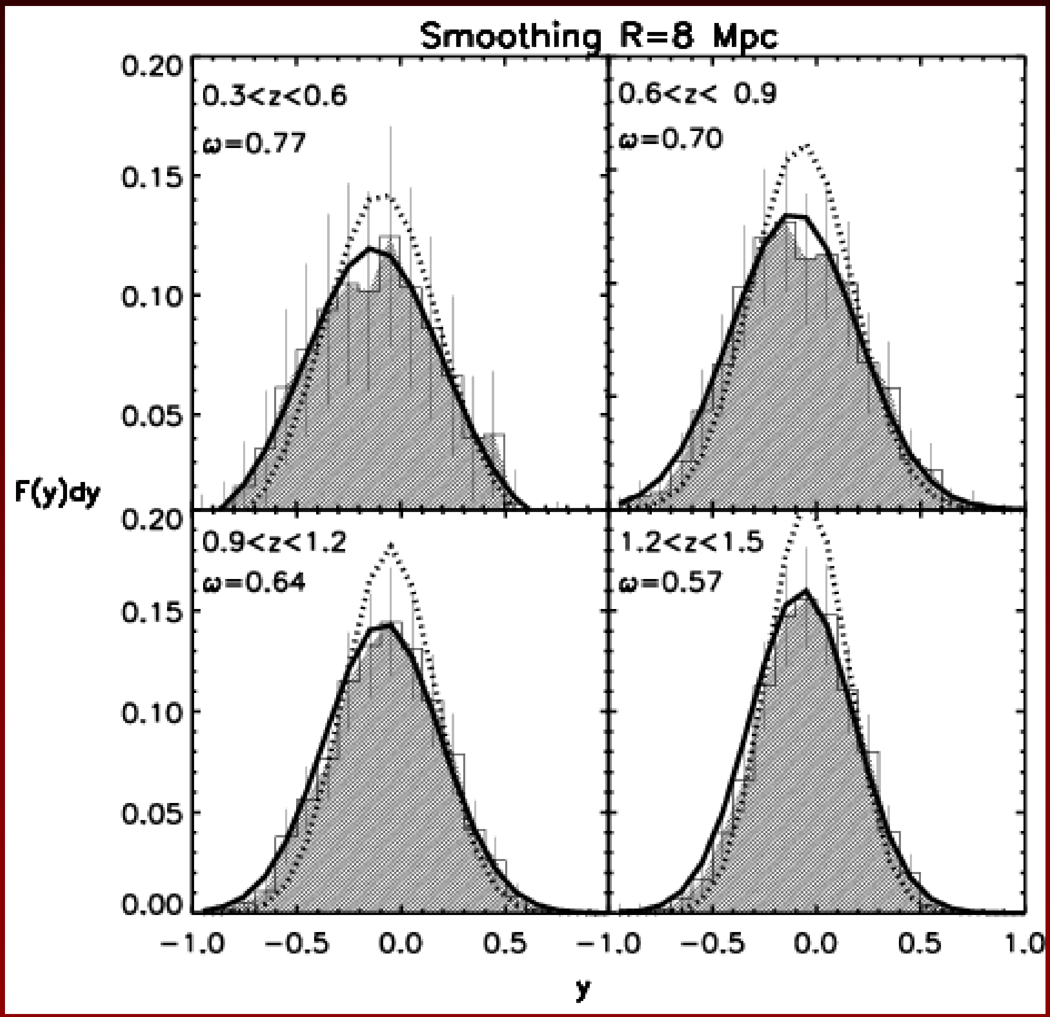
Problem: we measure galaxies in redshift space!

$$\sigma_z(R,z)$$

$$\sigma_z(z) = \sigma_r(0)D(z)[1 + \frac{2}{3}f(z) + \frac{1}{5}f(z)^2]$$

Kaiser 87

Is the lognormal PDF a good approximation?



ΛCDM Hubble Volume simulation (Virgo cons.)