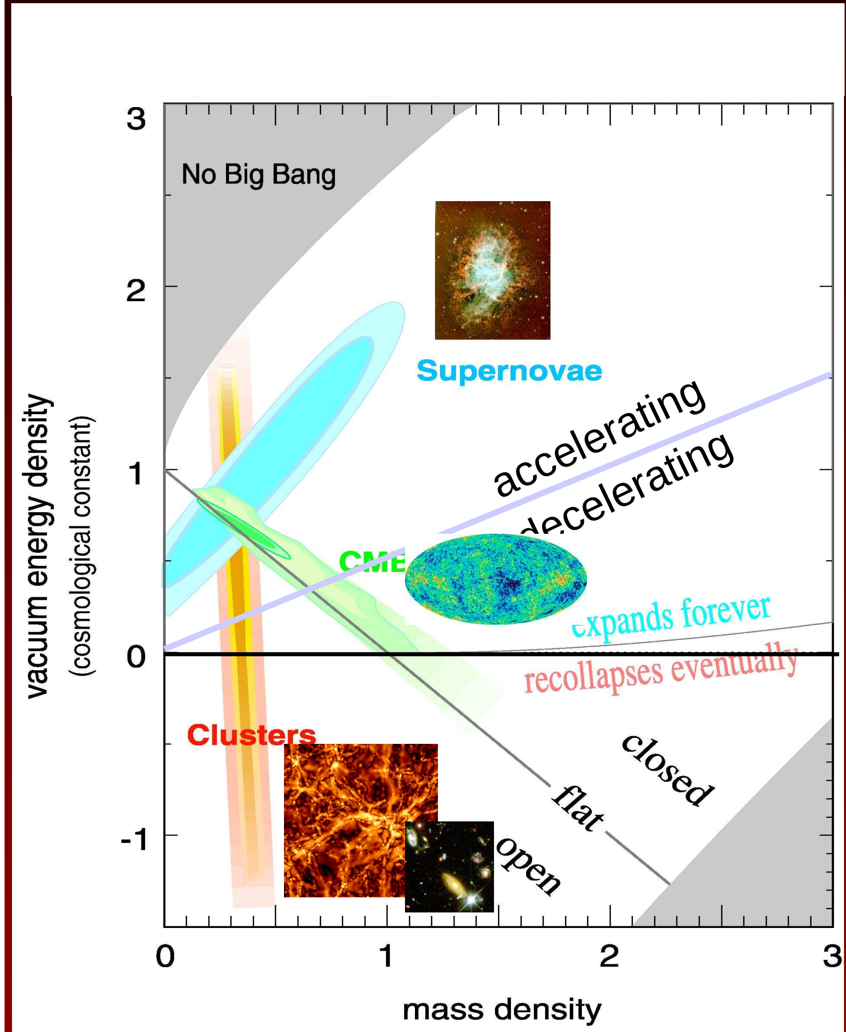
Testing gravity and cosmological models at z~1

Christian Marinoni

Centre de Physique Théorique
Université de Provence
Marseille

State of The Art



Un unprecedent convergence of results in cosmology over the last few years indicates that we live in a universe where:

- 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

The major constituents of the universe and many of the detailed physical mechanisms yet remain to be understood.

Would you spend the rest of your lives measuring to arbitrary precision something we don't know?

2008 Ap. JC : Hypothèses de Notre Modèle de l'Univers

Matière Noire, Énergie Noire

Gravity

Field equations

$$G_{\mu\nu} = \kappa T_{\mu\nu}$$

? ?

New source

New gravitational physics

Metric

RW line element

$$ds^2 = dt^2 - a^2[d\chi^2 + S_k(\chi)d\Omega^2]$$

?

Inhomogeneus universe

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***

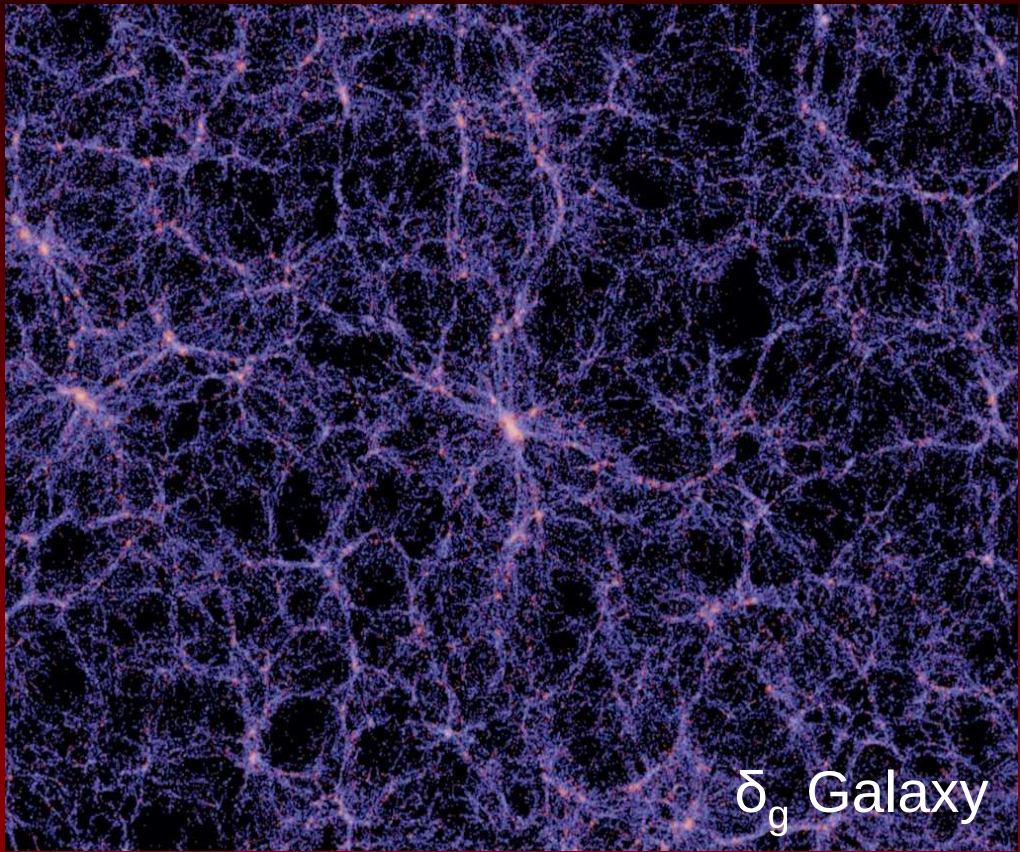
  - *The cosmological lensing of galaxy diameters*

  - *Counts of deep optical clusters VVDS+DEEP2*

Quelle relation entre fluctuations de MN et de baryons?

Quelle relation entre fluctuations de MN et de baryons?

Millenium Simulation



Springel et al. Nature 2005

- Problème formel:

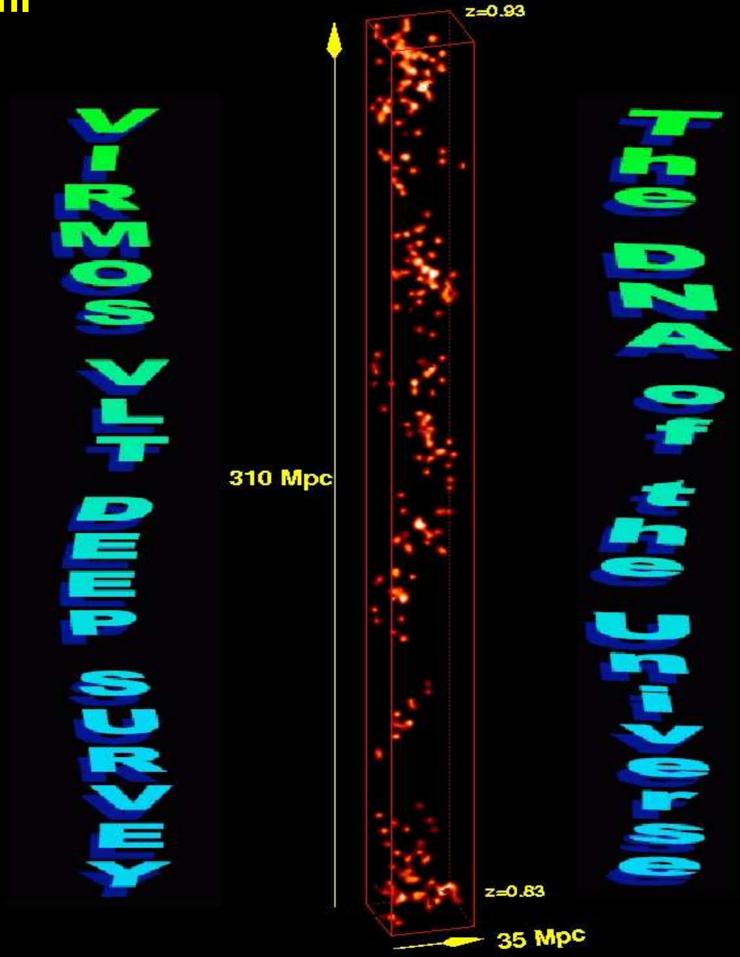
$$\boxed{\delta_g = \delta_g(\delta, z)}$$

Biais

Fonction fondamentale pour comparer les prédictions théoriques aux observations

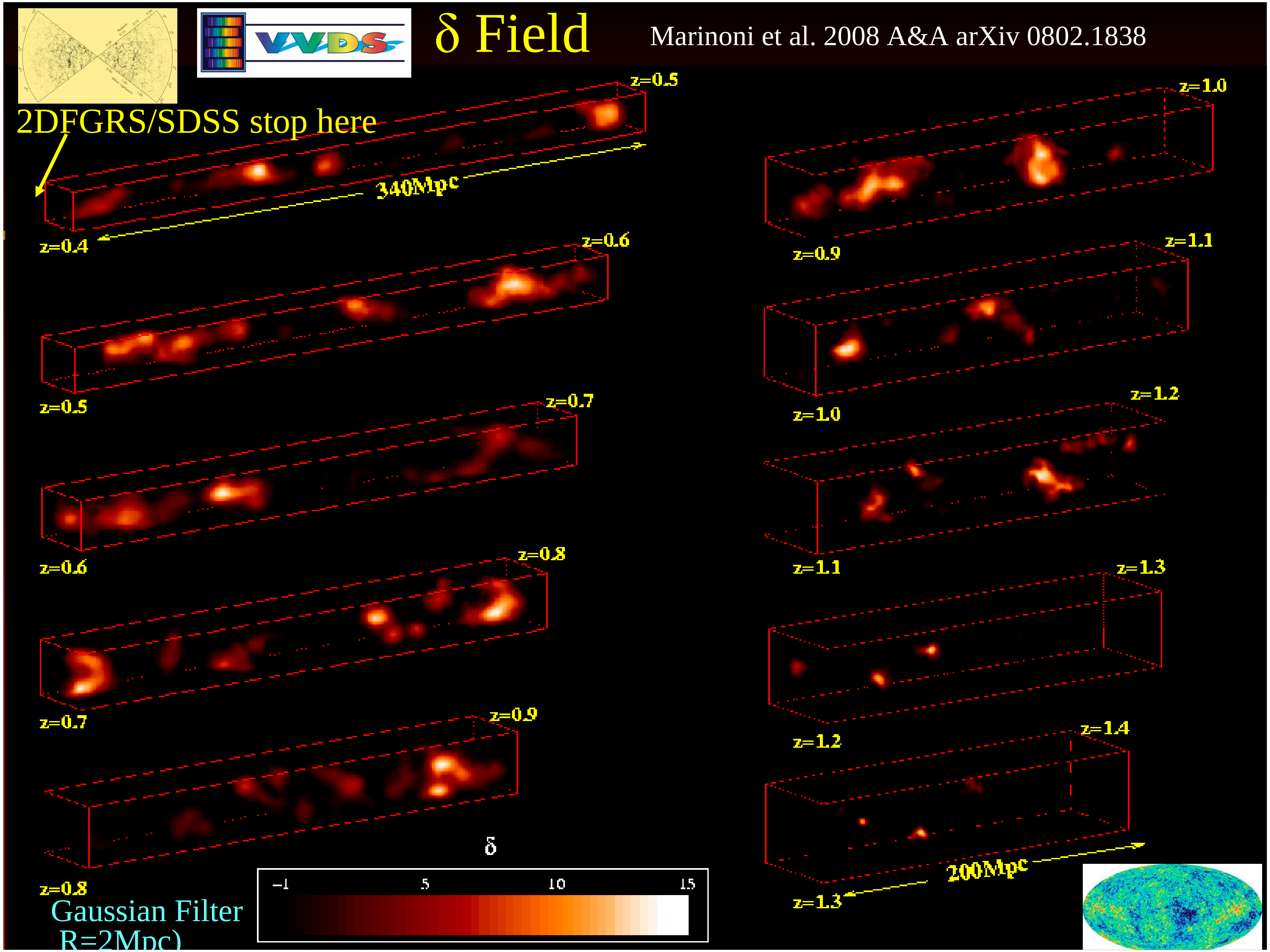
Massey et al. 2007 (ACS/COSMOS)
www.spacetelescope.org/news/html/heic0701.html

Mass Fluctuations

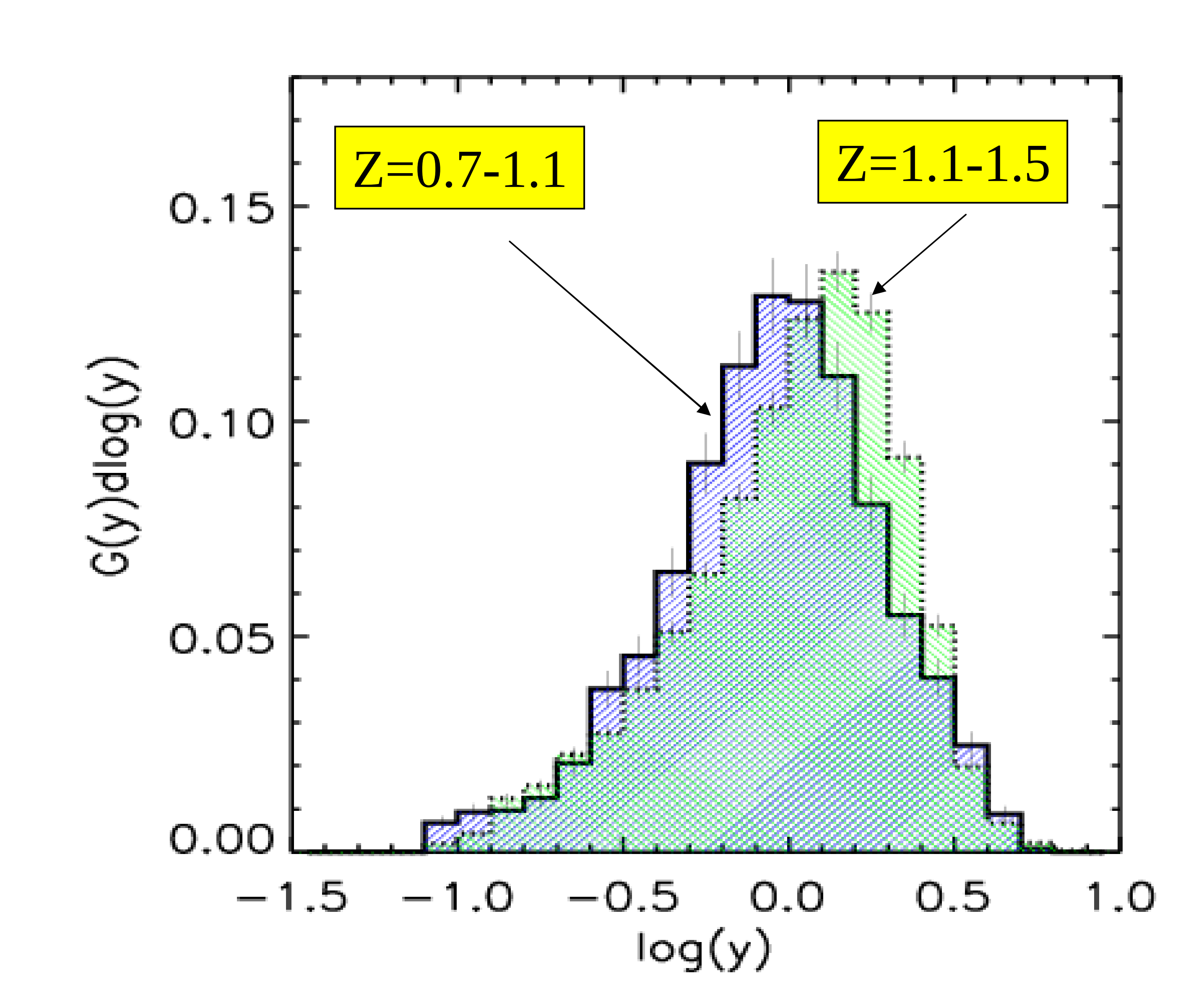


Galxy Fluctuations

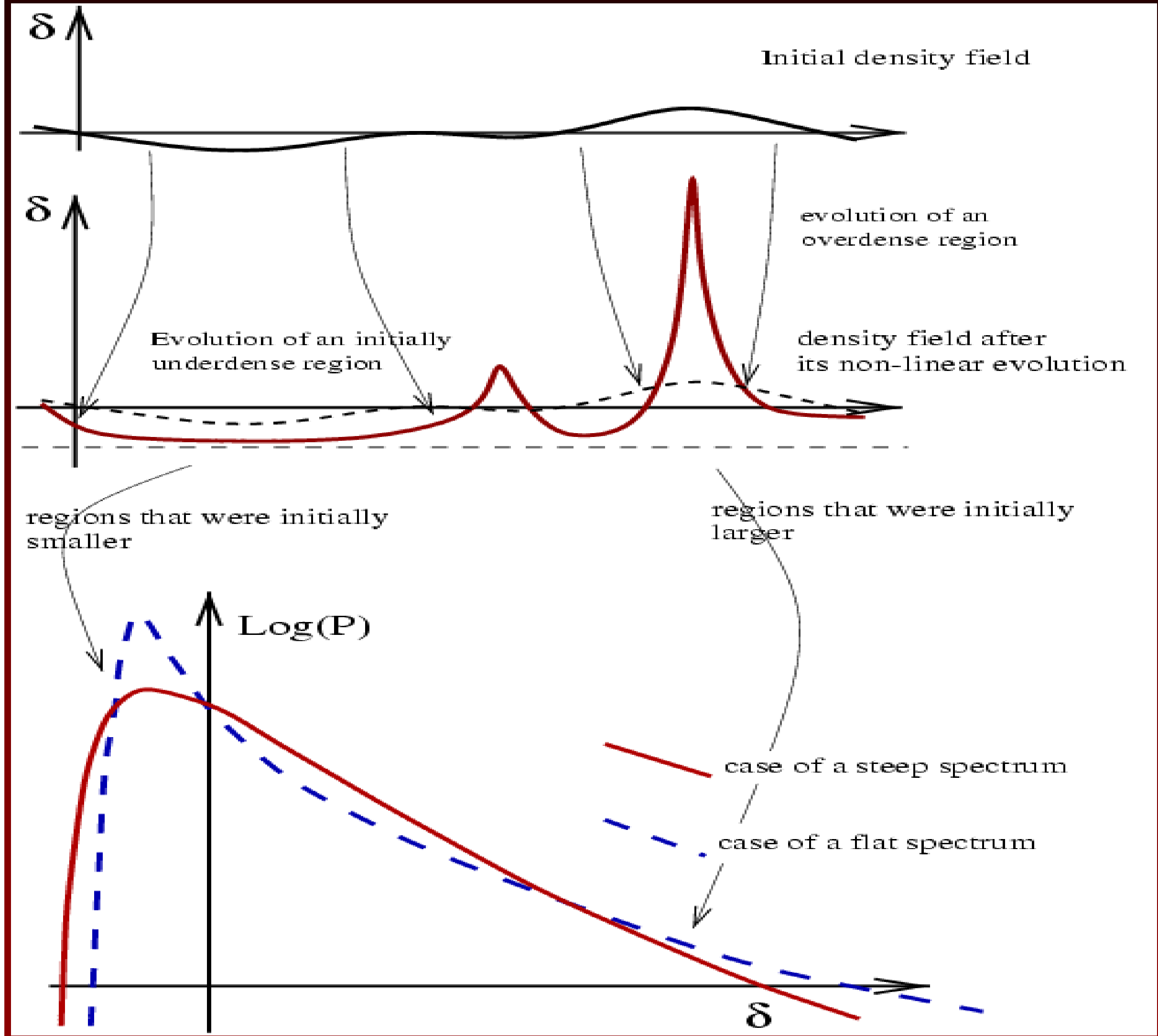
Marinoni et al. 2007 (VIMOS/VLT)
http://www.eso.org/outreach/press-rel/pr-2006/pr-45-06.htm


δ Field
Marinoni et al. 2008 A&A arXiv 0802.1838
VVDS
2DFGRS/SDSS stop here
340Mpc
z=0.4
z=0.5
z=0.5
z=0.6
z=0.6
z=0.7
z=0.7
z=0.8
z=0.8
z=0.9
z=0.9
z=1.0
z=1.0
z=1.1
z=1.1
z=1.2
z=1.2
z=1.3
z=1.3
z=1.4
200Mpc
δ
-1
5
10
15
Gaussian Filter
R=2Mpc)

The PDF of galaxy overdensities g(δ): Shape



A possible Interpretation

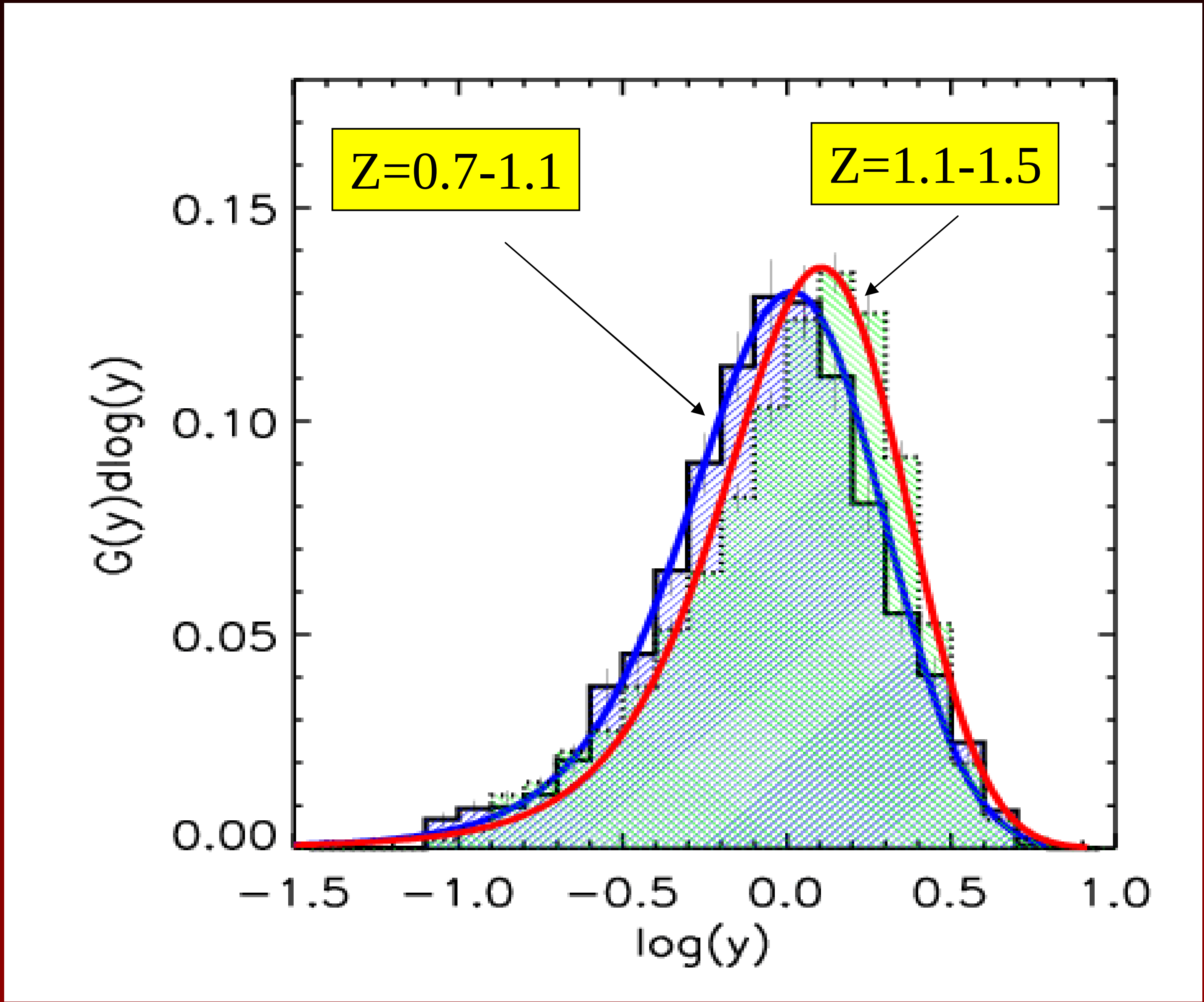


Gravitational instability in an <u>expanding</u> universe

$$\vec{v}(\vec{r}) \propto \int_V \delta(\vec{r}\,') \frac{\hat{r}-\hat{r}'}{|\vec{r}-\vec{r}\,'|^2} d^3\vec{r}\,'$$

Prédictions de la forme fonctionnelle du biais

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



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

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

Le biais n'est pas linéaire comme naïvement assumé par le théoriciens

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

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

Contraintes Cosmologiques de la Gravitation

Paradigme de l'Instabilité Gravitationnelle

Approximation Linéaire

Régime Newtonien

Matière Noire sans Pression

Perturbations Adiabatiques

Matière Noire

$$\ddot{\delta} + 2\frac{\dot{a}}{a}\dot{\delta} = 4\pi G\bar{\rho}\,\delta$$

Peebles 1980

Energie Noire

Solution non stable (et croissante)

$$\delta(x,t) = \delta_i(x)D(t)$$

Modèle théorique de
du biais matière - lumière

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

Marinoni et A&A al. 2005

$$\boxed{f(t) = \frac{d\ln\delta_g}{d\ln a}}$$

Fonction de croissance des perturbations

$$\boxed{S_3(t) = \left\langle \delta_g^3 \right\rangle_c / \left\langle \delta_g^2 \right\rangle^2}$$

Skewness des perturbations

Growth of CDM structures: A dynamical approach

Wang & Steinhardt (1998)
Linder (2005)

$$f(t) \approx \Omega_m(t)^{\gamma}$$

Local gravity

Global expansion

$$\Omega_m(t) = \frac{\Omega_m^0 a^{-3}}{H^2}$$

$$(H(t)/H_0)^2 = \Omega_M^0 a^{-3} + \Omega_X^0 a^{-3} \exp\left[-3\int_1^a w_X(a')d\ln a'\right]$$

$$w = \frac{p_x}{\rho_x}$$

-Growth of perrturbations is damped in low matter density or accelerated universes

Within the Standard Model, one can use f to constrain cosmological parameters

Note that most of the cosmological tests (CMB, SNIa) probe the integral of H

$$Obs(z) \propto \int \frac{H_0}{H(z)} dz$$

An alternative view : F is a diagnostic to test if the accelerated expansion originates from a non minimal modification of GR

Inhomogeneous Matter Gravity

$$f(t) \approx \Omega_m(t, \vec{p})^{\gamma}$$

Homogeneous Background Expansion

Different gravitational theories are tuned to reproduce the observed H(z). However, they predict different γ → different growth rate of structure

$$\text{Standard } \Lambda \text{ Paradigm} \quad \rightarrow \quad \gamma = 6/11$$

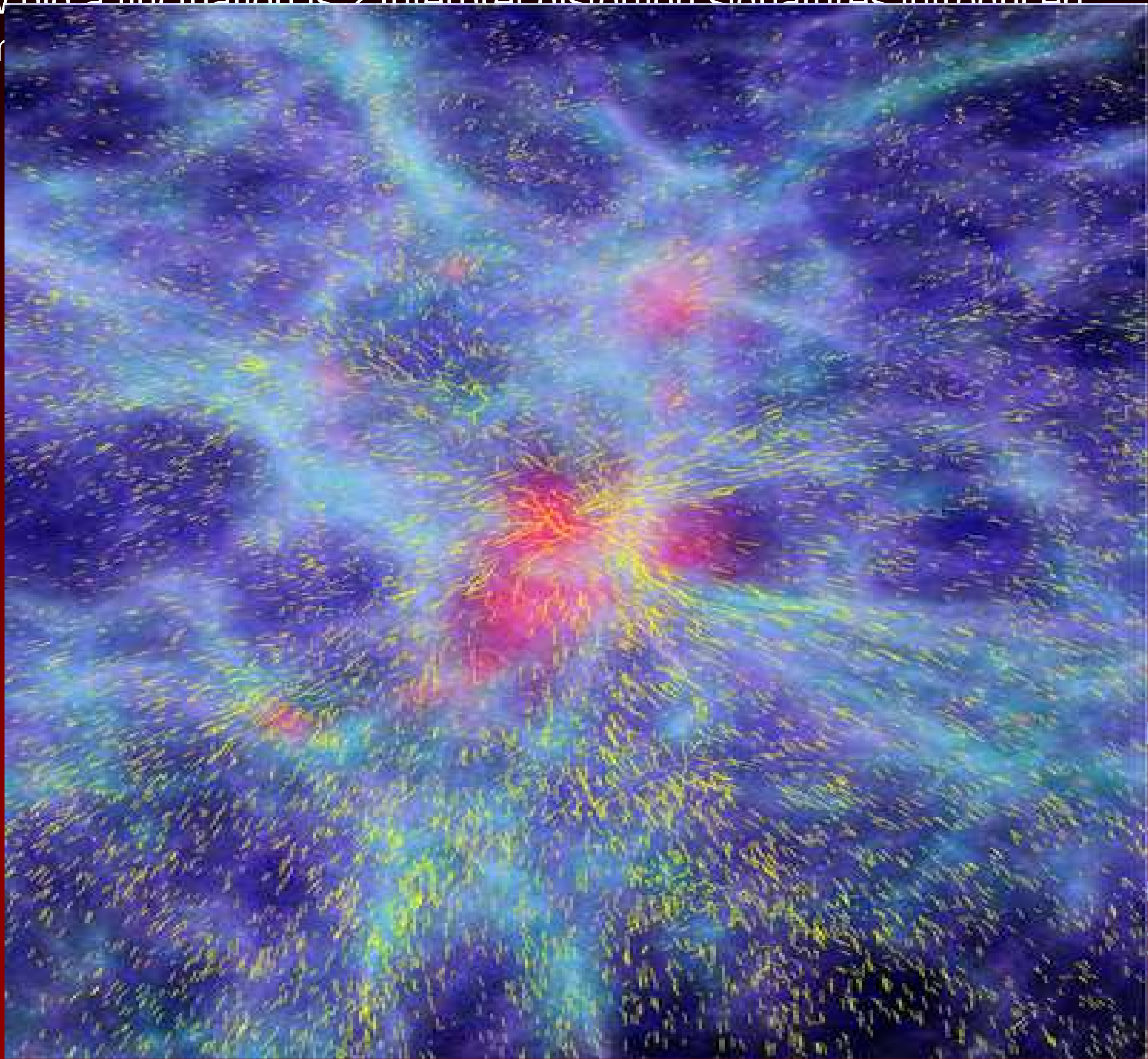
$$DGP \text{ (Dvali et al. 2000, Lue et al. 2004)} \quad \rightarrow \quad \gamma = 2/3$$

In principle, f can reveal the physical origin of the acceleration

Any discrepancy between measurements of the growth index and the values predicted using cosmological parameters inferred by purely geometrical tests of cosmology is a smoking gun for new gravitational physics beyond GR

How to extract f with large scale galactic dynamics?

How big a fluctuation is ? Interpret distortion signatures introduced by m



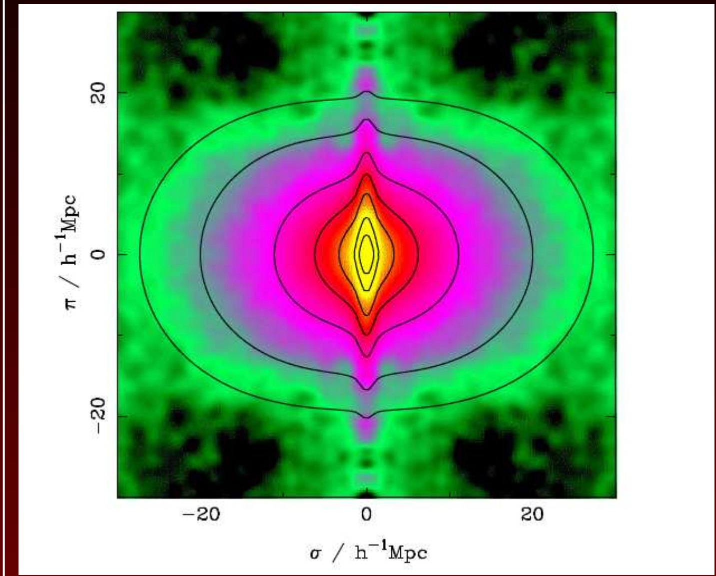
Small Scales

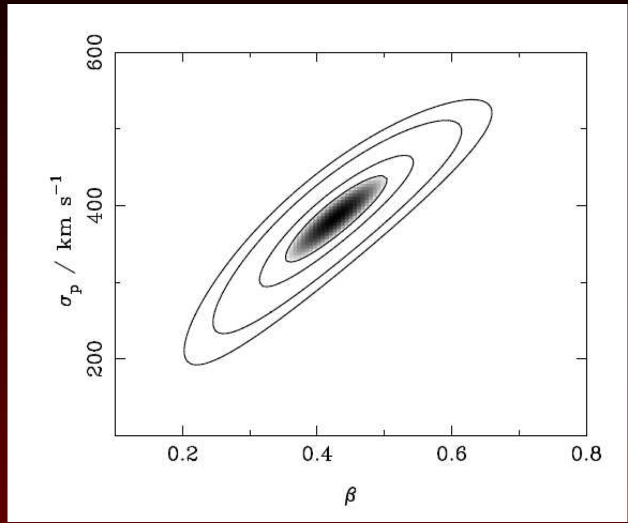
ndom motions
rease power
small scales
ng the L.o S.

Large Scales

ulk motions
crease power
n large scales
erpendicular
o the L. o S.

Redshift distortions in the correlation maps : Results





2dFGRS

(Colless et al. 00)

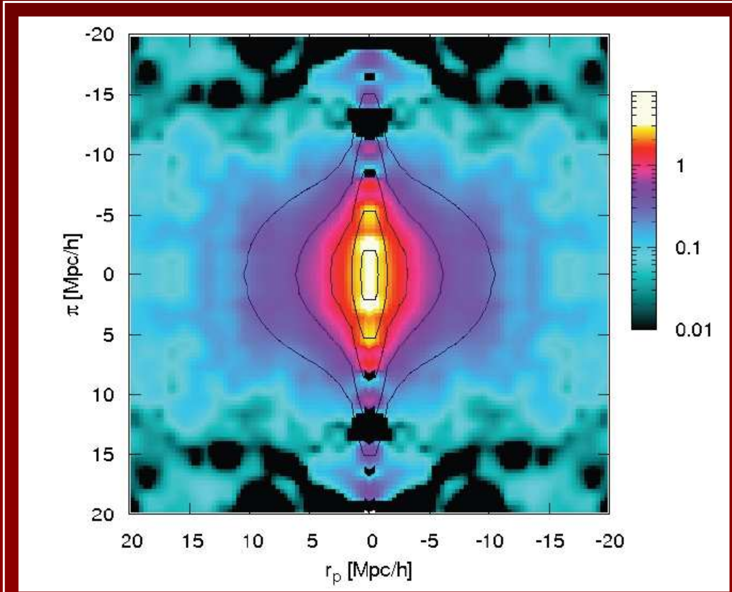
<Z>=0.1

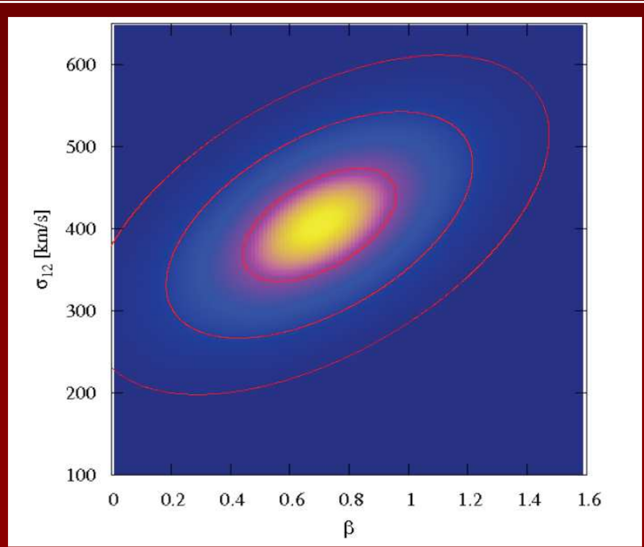
250,000 galaxies

f=0.5±0.1

σ=390±50 km/s

(Peacock et al. 2001, Nature)





VVDS

LeFevre et al. 05

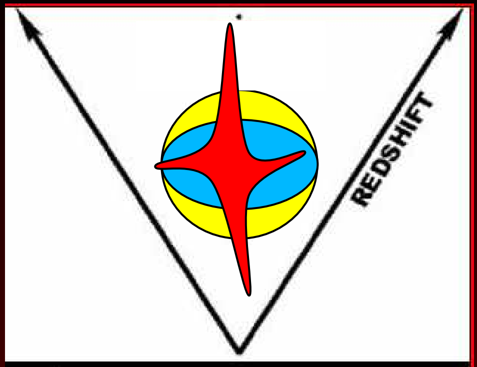
<Z>=0.75

10,000 galaxies

f=0.9±0.4

σ=400±50 km/s

(Guzzo, Pierleoni, Branchini, LeFevre, Marinoni et al. 2007 Nature submitted)



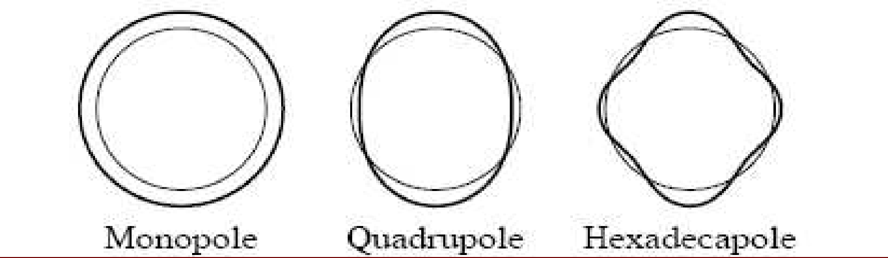
Method : Measure correlation of fluctuations in radial and transverse direction

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

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



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

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

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

$$\boxed{\beta = \frac{f}{b}}$$

Hamilton 1998

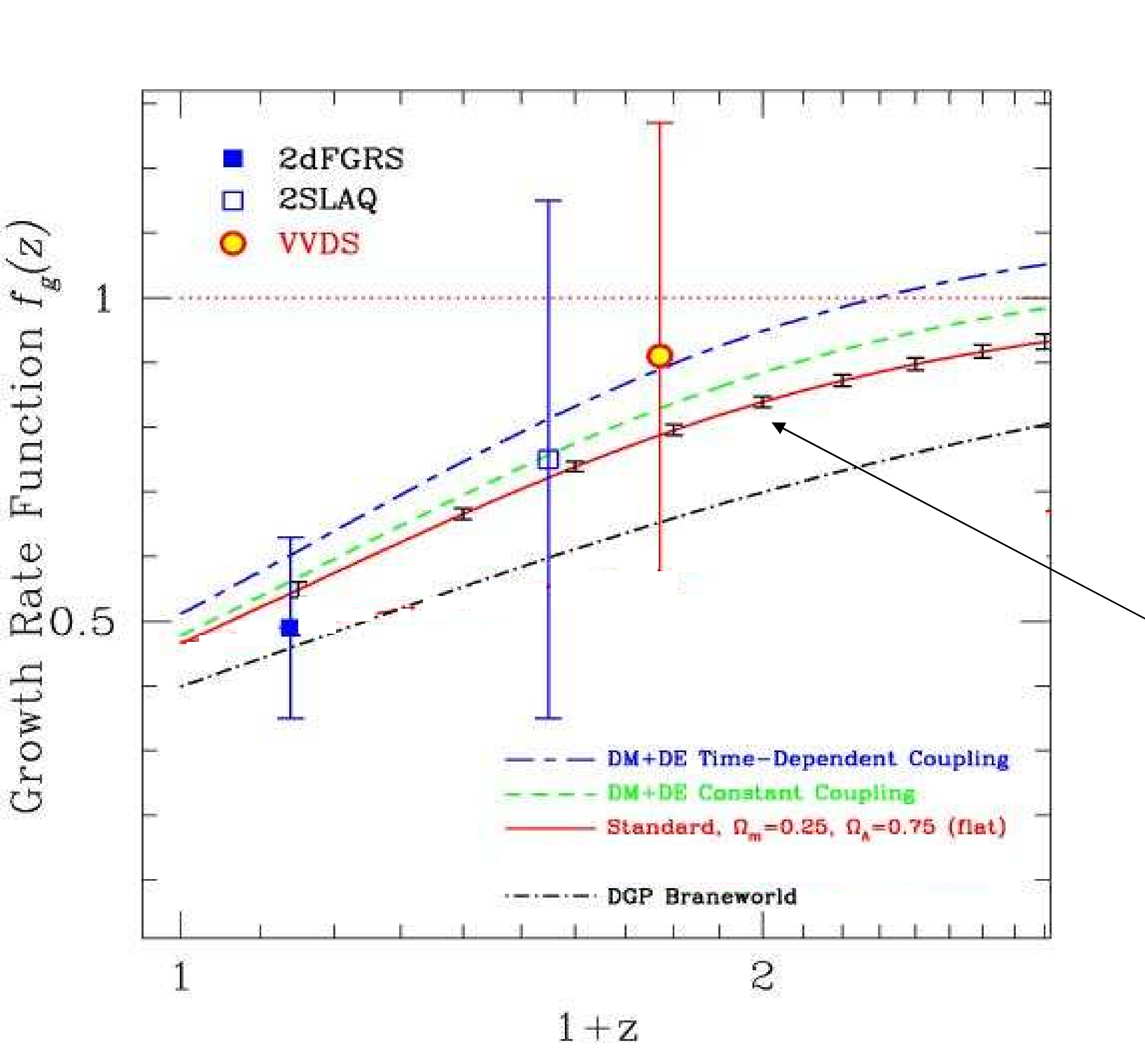
Non Linear Model

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

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

f = PDF of relative velocityies of galaxy pairs
σ = describes small-scale thermal random motion

Constraining the physics behind acceleration



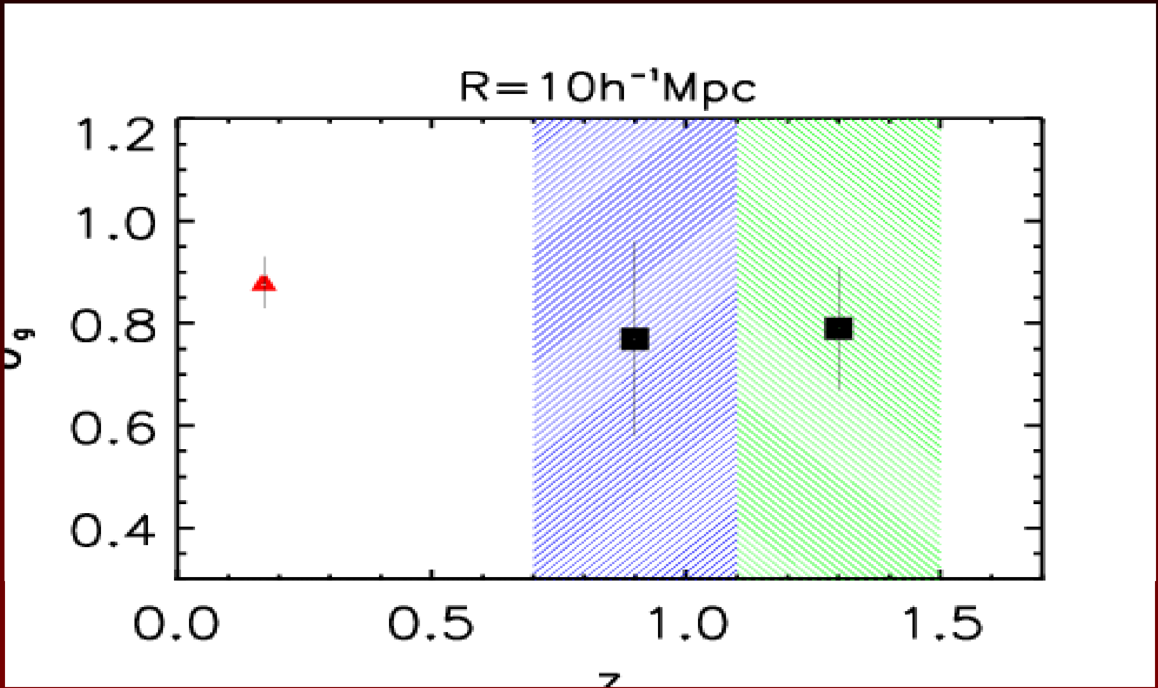
In linear theory

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

In principle, f can reveal the physical origin of the acceleration

Predicted constraints from SPACE/Euclide missison

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



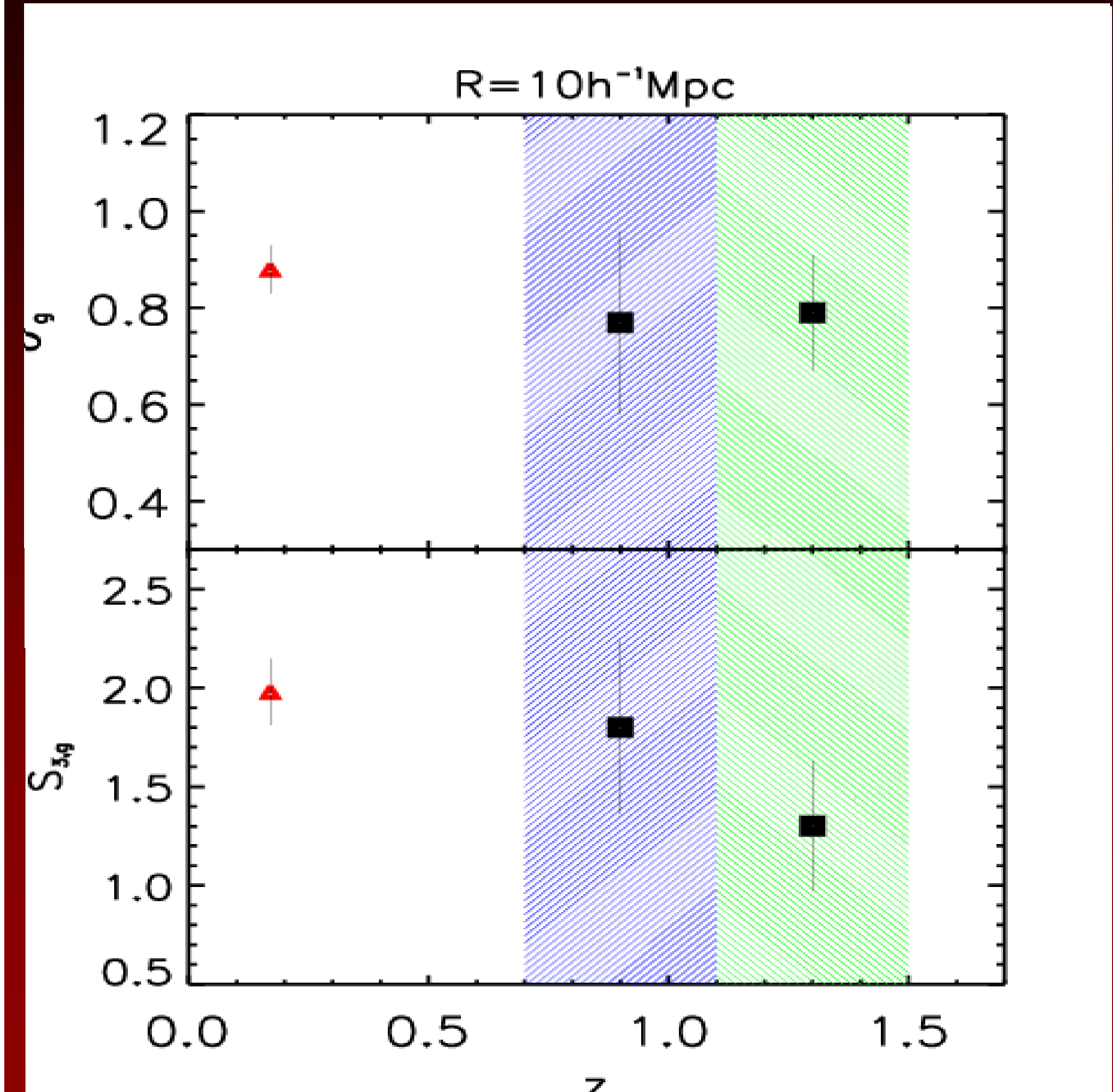
Second Moment

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 nowdays

Marinoni et al. A&A 2008 in press arXiv:0802.1838

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



Marinoni et al. A&A 2008 in press arXiv 0802.1838

Second Moment

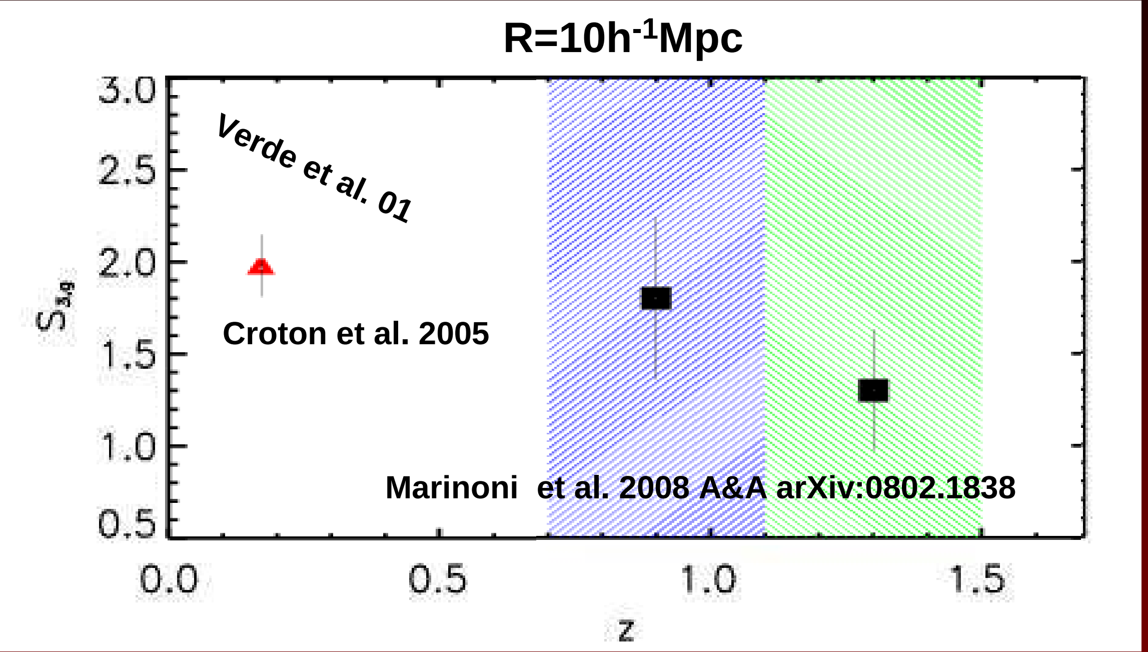
Fluctuations in the visible sector have frozen over ~2/3 of the history of the universe

The Young universe was as much inhomogeneous as it is nowdays

Third Moment

Galaxy distribution was significantly non Gaussian even at early times

Testing gravity with third order statistics : Skewness



Mass skewness

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

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

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

Conclusions:

Biasing is non-linear at the level we predict at high z

→ ΛCDM predictions are consistent with data over 9Gyrs

Biaising is linear as often naively assumed in literature

→ One need to question gravity …… or local measurements

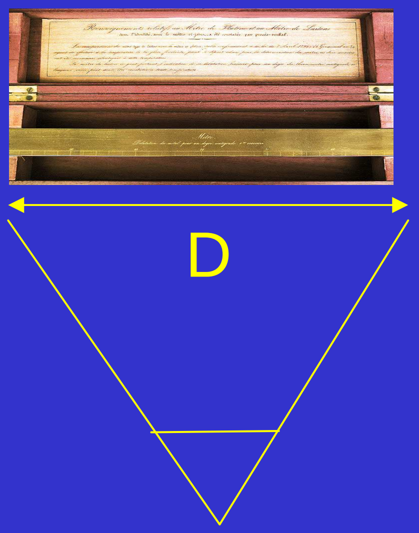
Metric constraints using the kinematics of high redshift disc galaxies

Marinoni, Saintonge, Giovanelli et al. 2007 A&A , 478, 41
Saintonge, Master, Marinoni et al. 2007 A&A, 478, 57
Marinoni, Saintonge Contini et al. 2007 A&A , 478, 71

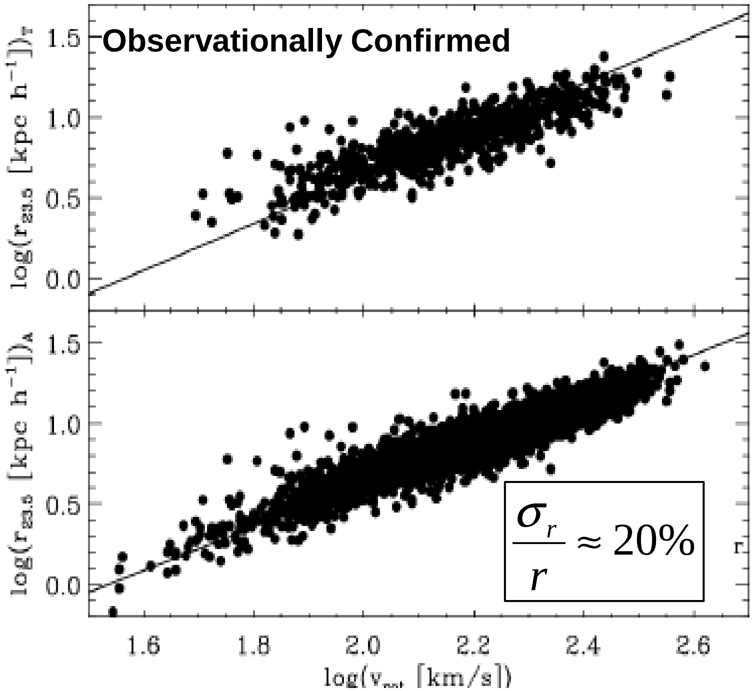
Standard Rod Selection

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

Angular Diameter Test



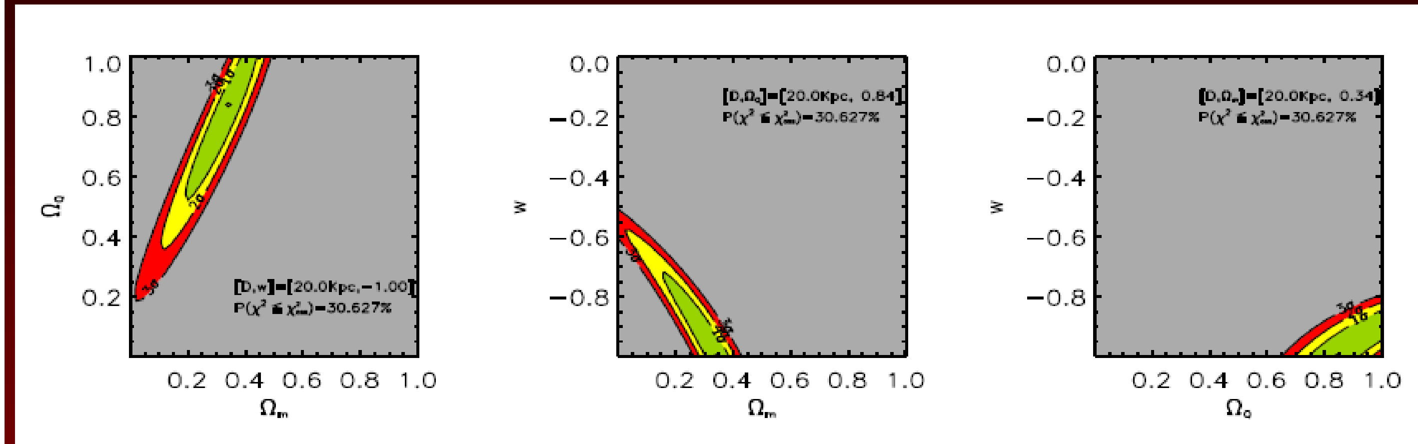
$$\theta(z) = \frac{D(z)}{d_A(z,\Omega)}$$



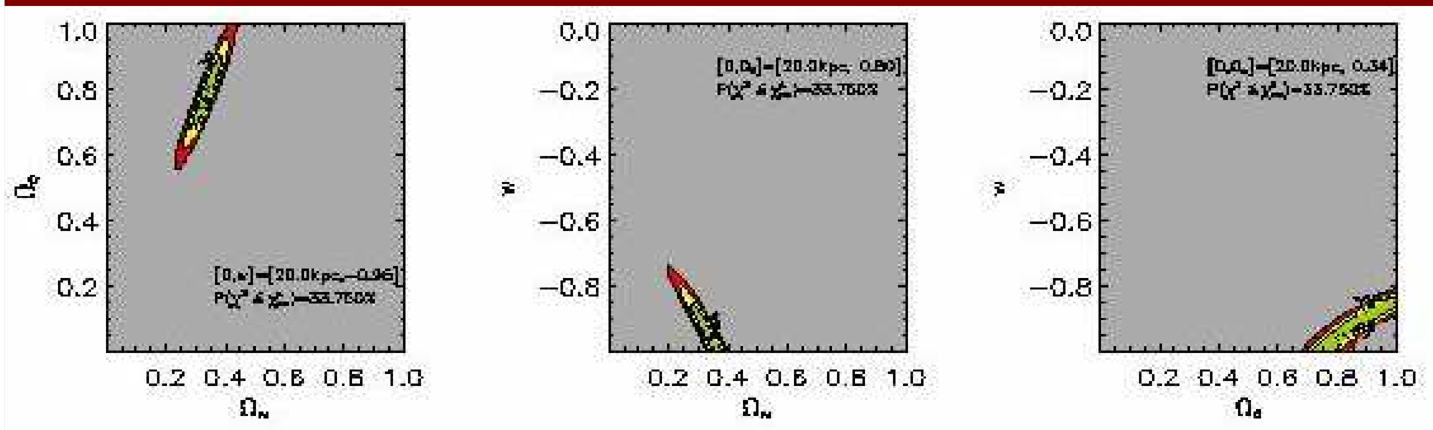
Saintonge et al. 2008 A&A,478, 57

The angular diameter test with high-velocity rotators

Predictions for V>200km/s (big) galaxies



zCOSMOS (1 deg^2):
~ 1300 rotators
and $(\sigma_D/D)_{int}$=20%



full VVDS (16 deg^2):
~ 20 000 rotators
and $(\sigma_D/D)_{int}$=20%

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)

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

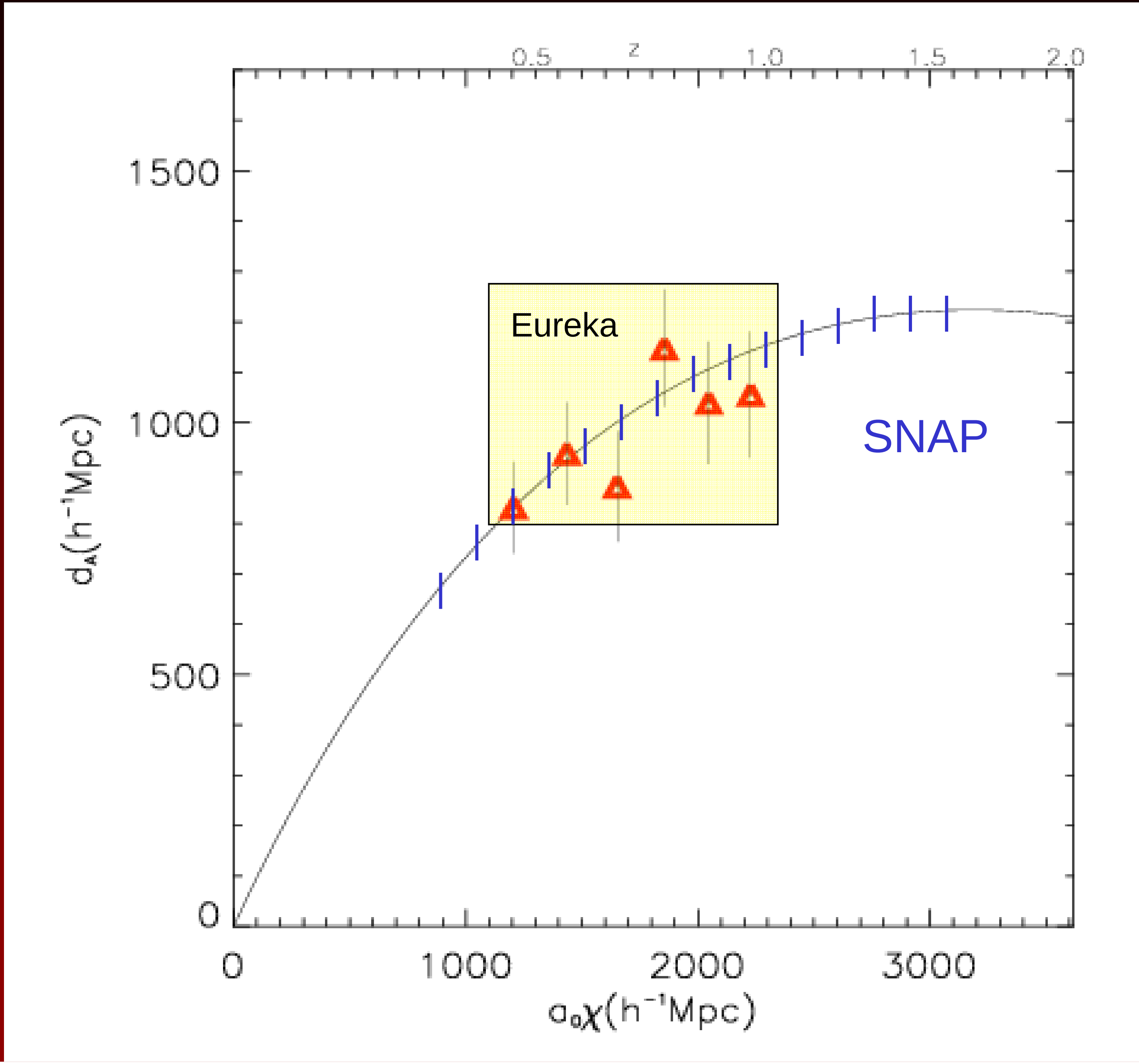
where

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

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

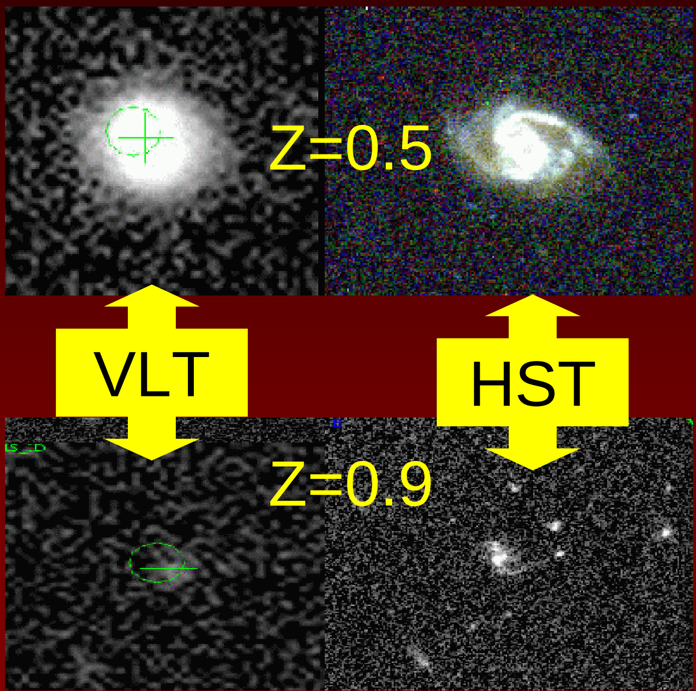
Violation of consistency might indicate Non-RW geometry

Simulation de la précision du Test du Principe Cosmologique

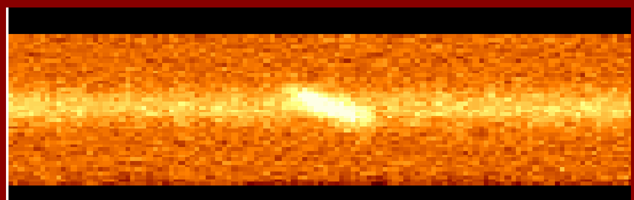


Implementation Strategy:

HST/Cosmos imaging survey:



HR Spectroscopy (VIMOS)



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

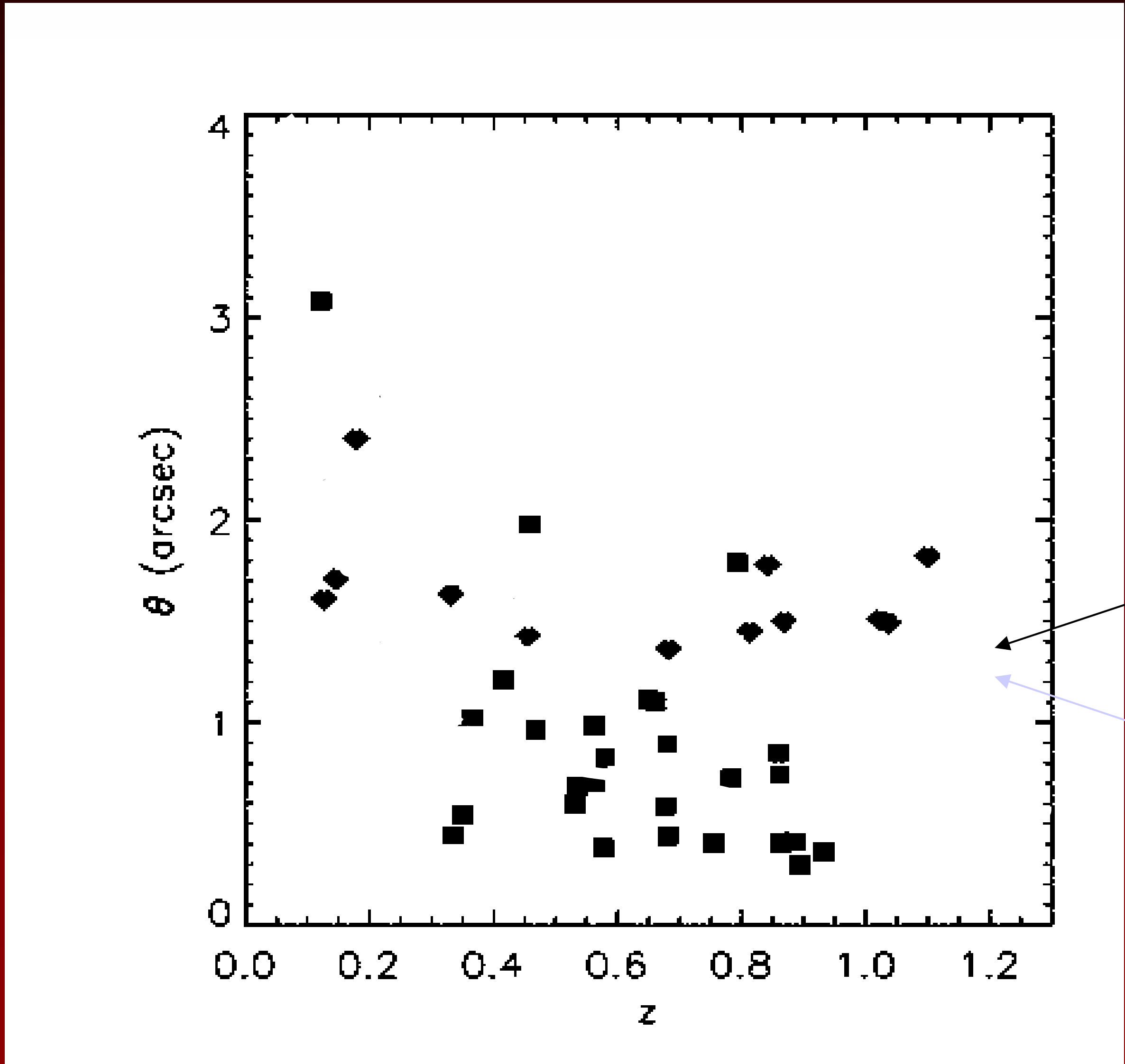
Very Quick (…but large) Survey!!

~1300 rotators down to Iab 22.5 in only 30h

Retarget in High spectroscopic resolution zCOSMOS discs with known <u>emission lines</u> and <u>redshift</u>

Preliminary data

Standard Rod Selection



Comparison with the predicted angular evolution in the standard ΛCDM background

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

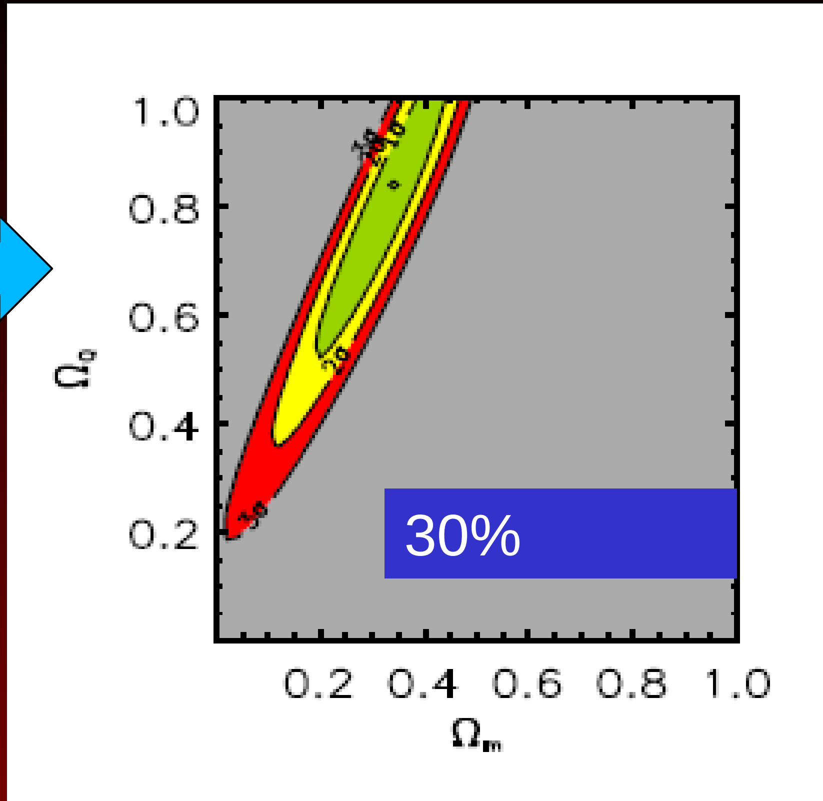
Best fitting model

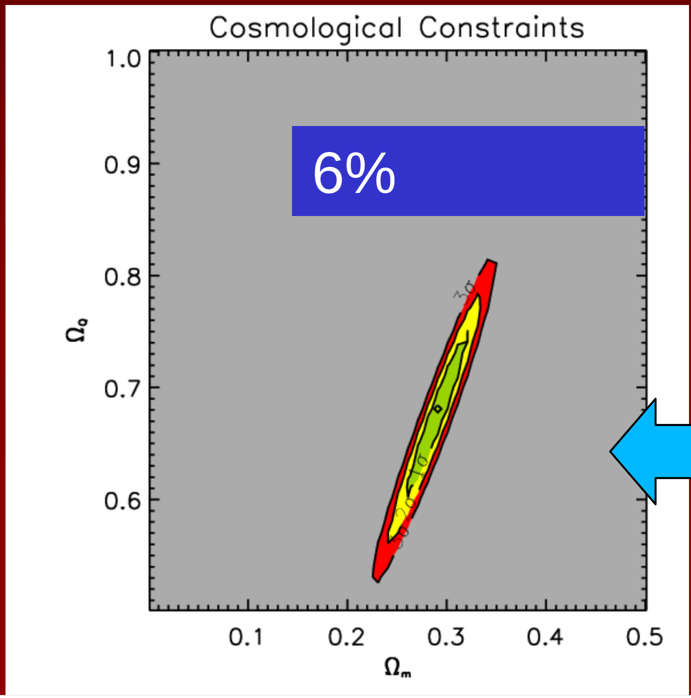
ΛCDM

Réalisation du test

Projets Eureka au VLT accepté par ESO !
(P.I. L. Tresse)

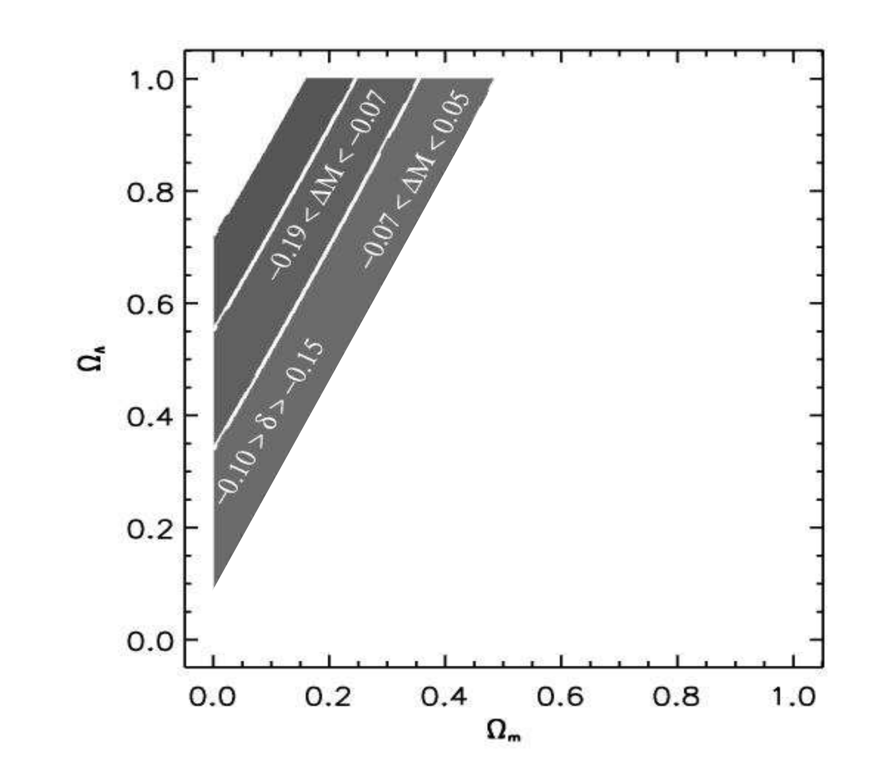
Demande d'ANR jeunes en cours d'évaluation
(Coordinateur C. Marinoni)





Participation à la définition de la nouvelle science faisable avec le spectrographe EAGLE pour le EELT
(P.I. Cuby)

Cosmological Constraints from Preliminary data



Observational constraints:

1) luminosity emitted per unit mass was higher In the past.
2) SB evolution as inferred from data

Which is the region of the cosmological parameter space which is compatible with these external constraints?

By imposing that luminosity emitted per unit mass was higher in the past we can exclude :

* SCDM (EdS) at 3σ
* OCDM (Ω_M=Ω_T=0.3) at more than 1σ

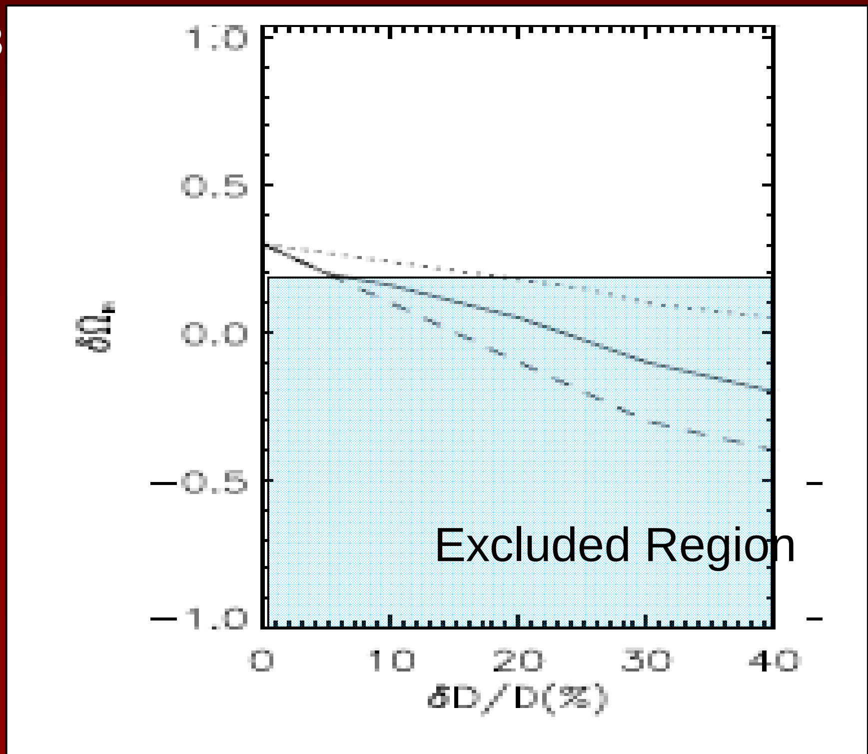
with 30 rotators at <z>=1 only !!!

EVOLUTION

According to theory (analytic models and simulations) big baryonic discs already completed their evolution before z=1

Chiappini, Matteucci & Gratton 1997
Boissier & Prantzos 2001
Bowens & Silk 2001
Ferguson & Clarke 2003
Somerville et al. 2007

Theory predicts that the rotation velocity at a given stellar mass is only about 10% larger at z~1 than at the present day

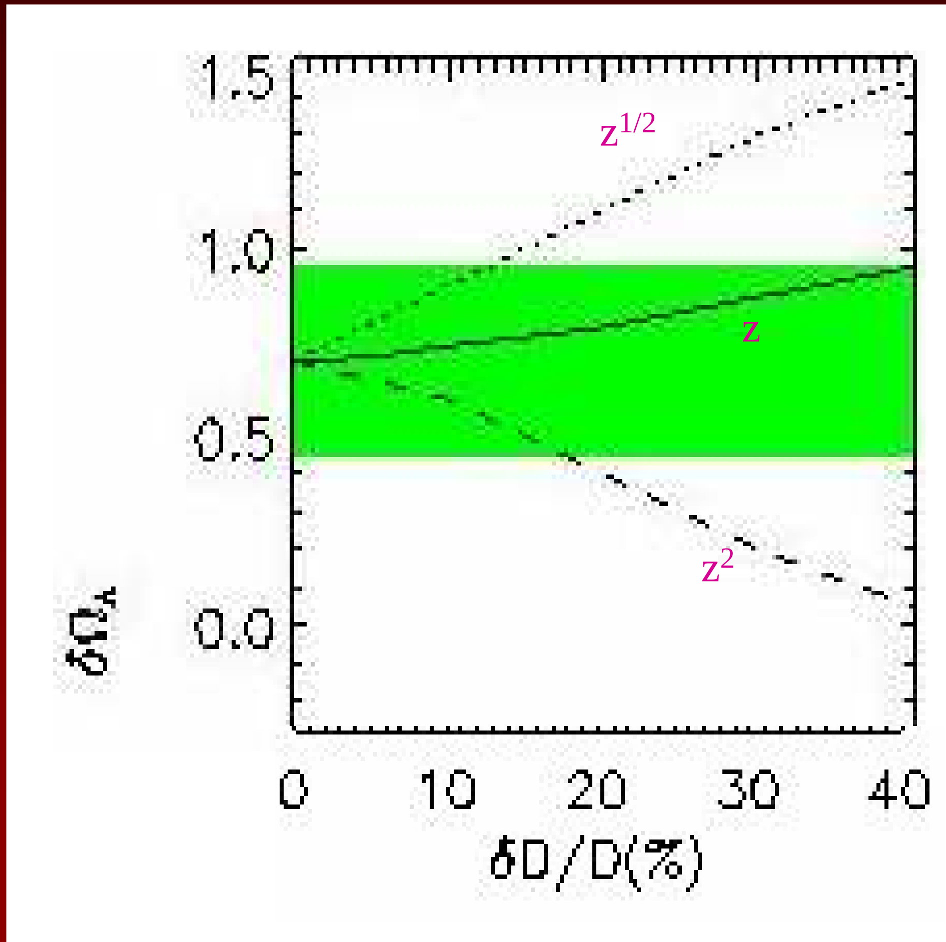


Evolution Diagnostic

Does evolution bias results?

Suppose there is a mild evolution ? $D(z) = D(0) + D^{'}(0)z$

DE equation of state parameterization



Why Galaxy Clusters?

"The panel concluded that the cluster abundances had in principle <u>higher potential than SN and BAO</u>. Not only in constraining cosmological parameters, but also because the combination of growth and distance tests can provide a fundamental test of GR."

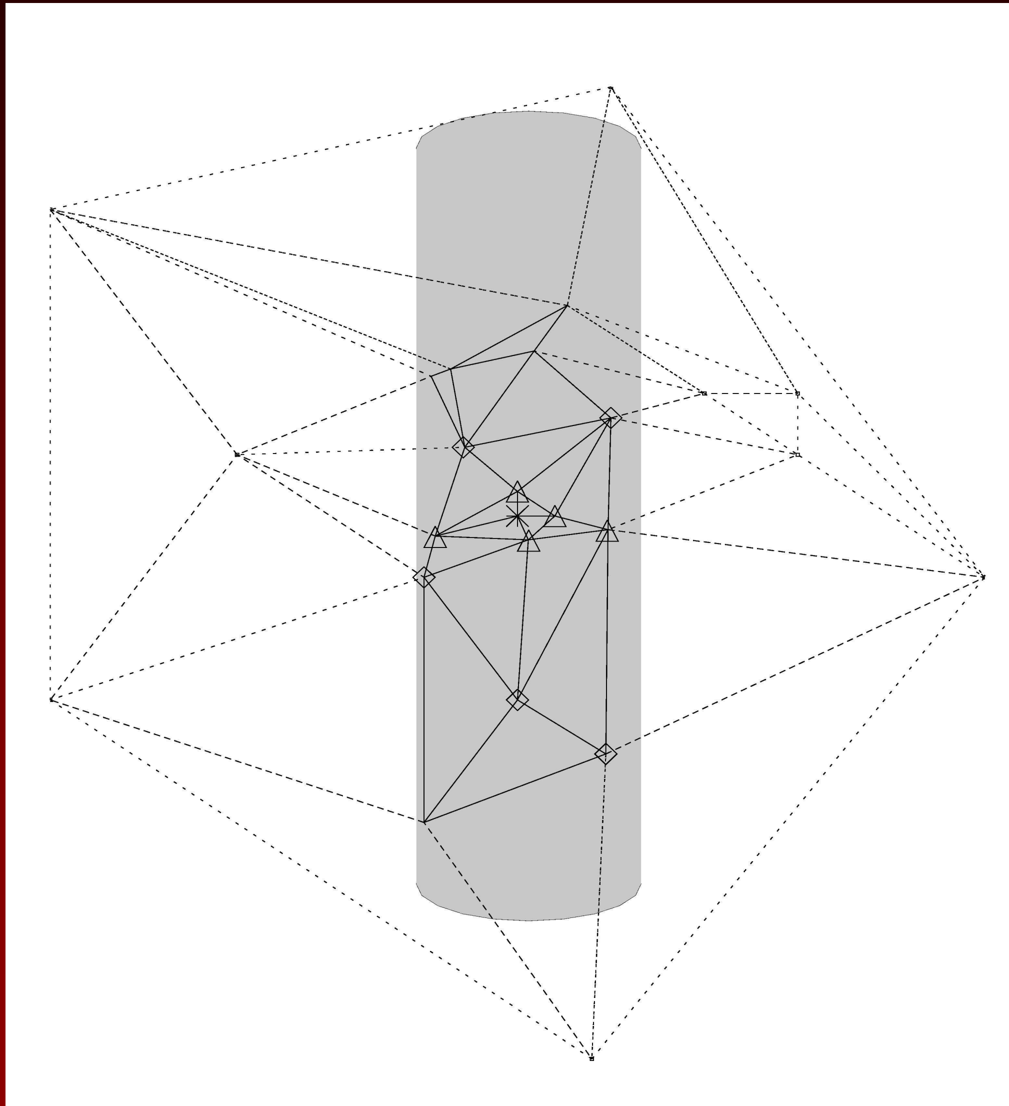
DETF panel

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

<u>Observational Issue</u> : identifying and reconstructing virialized systems in cosmological surveys?

Reconstructing clusters in deep spectroscopic surveys

3D Voronoi-Delaunay Geometry



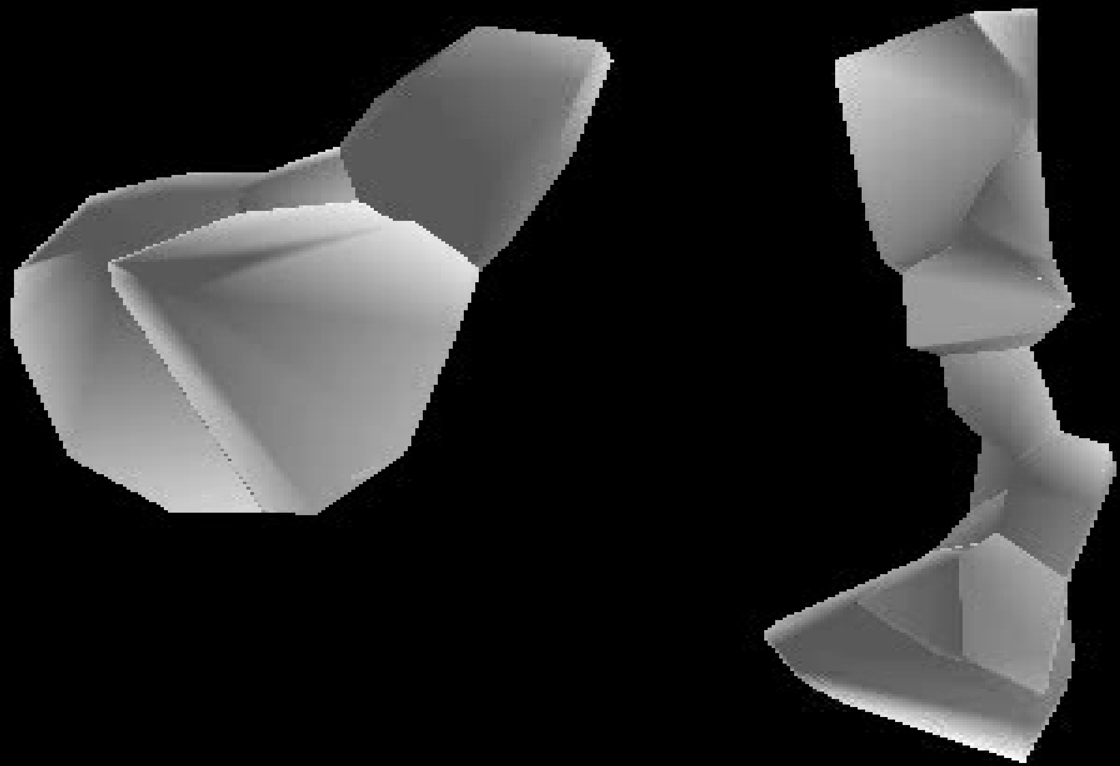
$$\Sigma_0 \propto r^{\alpha}$$

Marinoni, Davis, Newman & Coil 2002

3D Voronoi Representation of a group with 10 galaxies

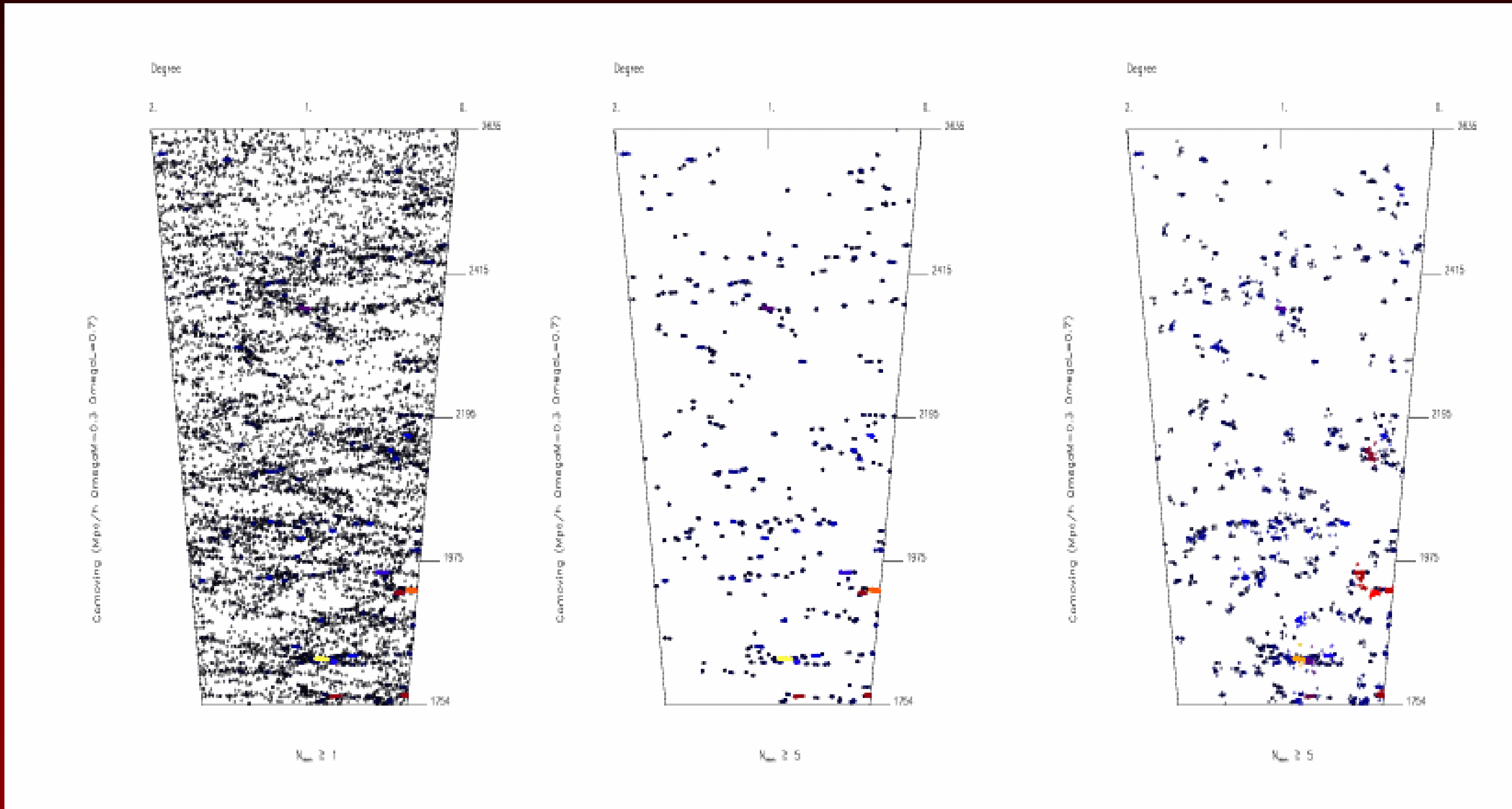
Real space

Redshift space



Performances of the reconstruction scheme

Millenium Simulation



Real Groups

Reconstructed Groups

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:

$$\frac{dn}{dM} = -0.315 \frac{\rho_0}{M} \left(\frac{1}{\sigma_M} \frac{d\sigma_M}{dM} \right) \exp\left\{ -[0.61 - \log(g_z \sigma_M)]^{3.8} \right\}$$

Jenkins et al. 2001

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

power spectrum (σ_8, n)

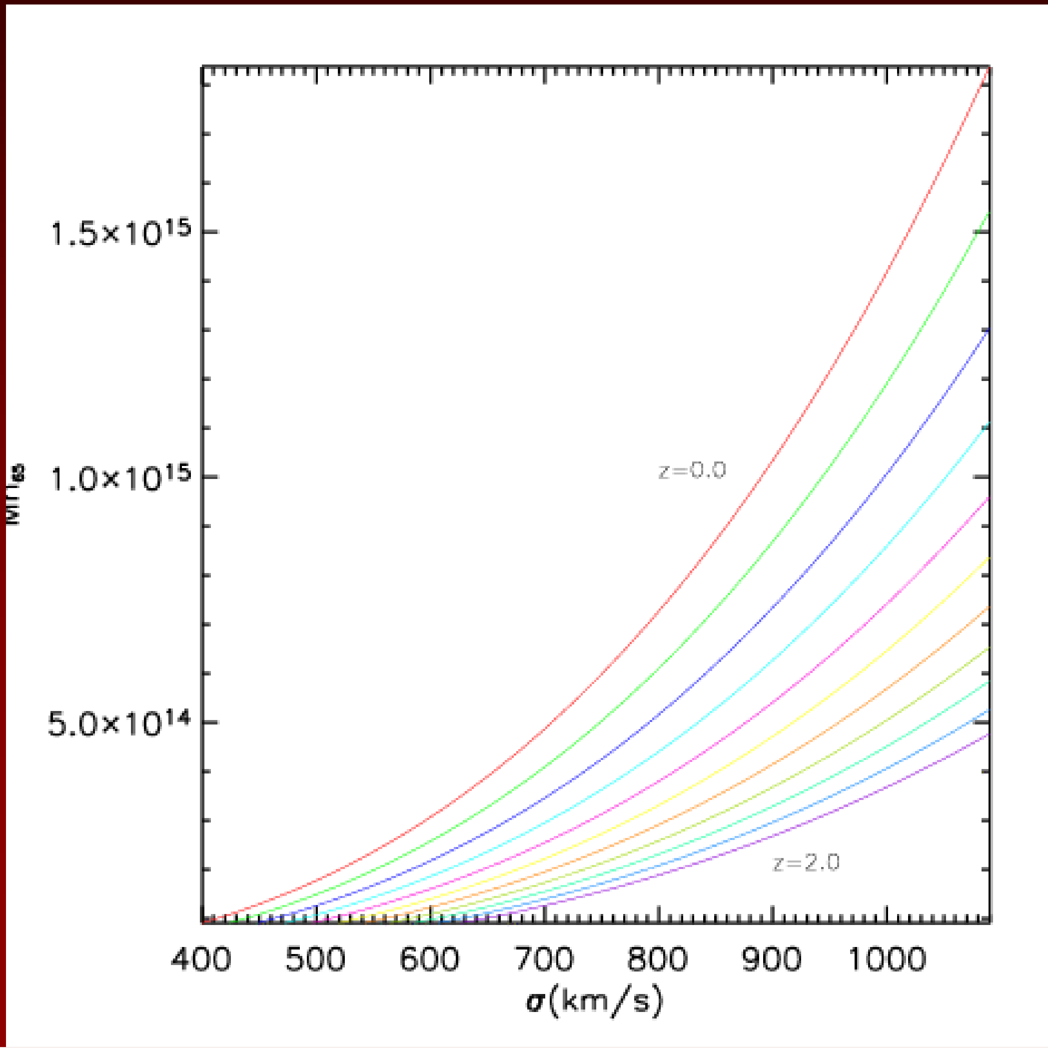
growth function $(\Omega_{m,} \Omega_{X,} w)$

Velocity Function Evolution

Mass is not an observable!
Use velocity dispersion

Newman, Marinoni & Davis 2003

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



Velocity Function Evolution

Mass is not an observable!
Use velocity dispersion

Newman, Marinoni & Davis 2003

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

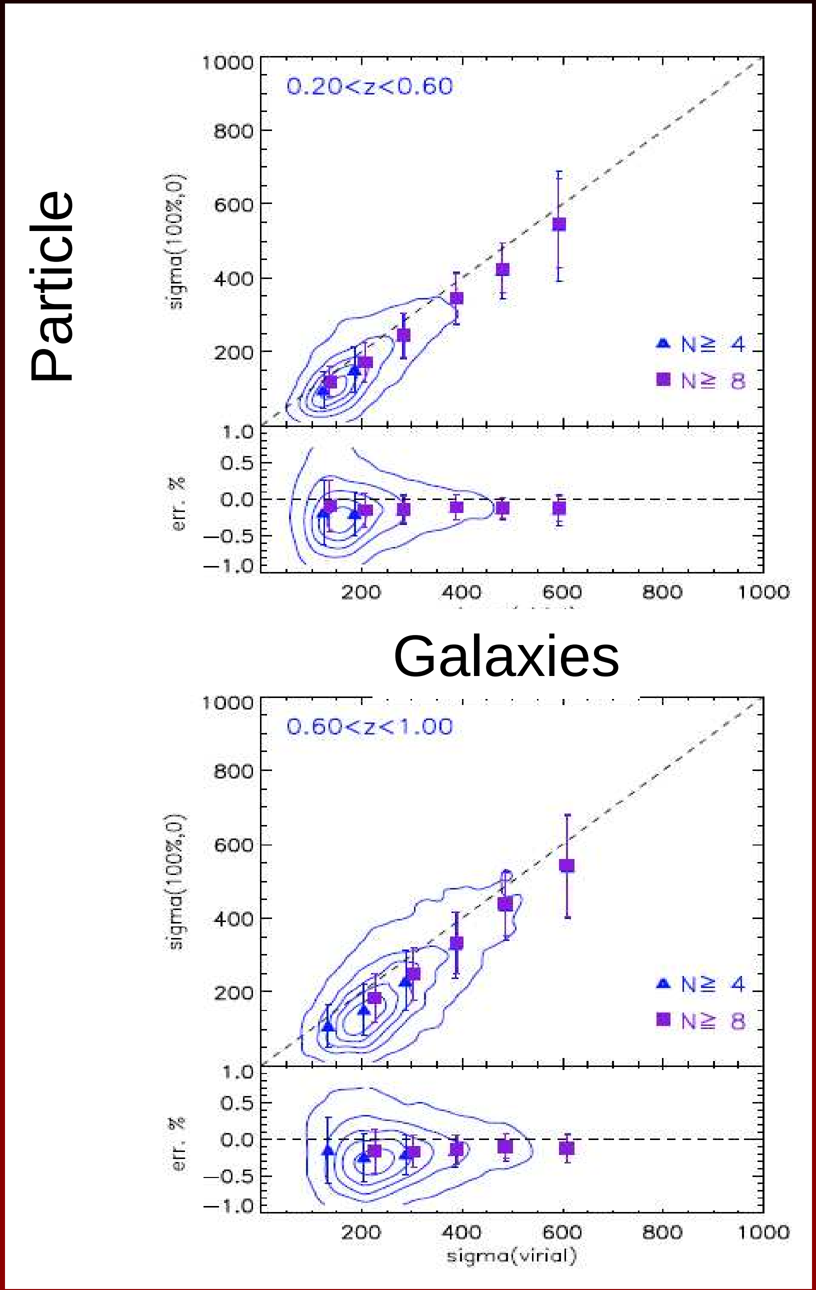
Theoretical Issues

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

Observational Issues

Velocity-velocity calibration

Velocity-Velocity calibration



(O. Cucciati et al. in preparation)

Millenium Simulation Mocks
mimicking the VVDS

33% sampling rate

σ-σ relation calibrated to 8%

Velocity Function Evolution

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

Theoretical Issues

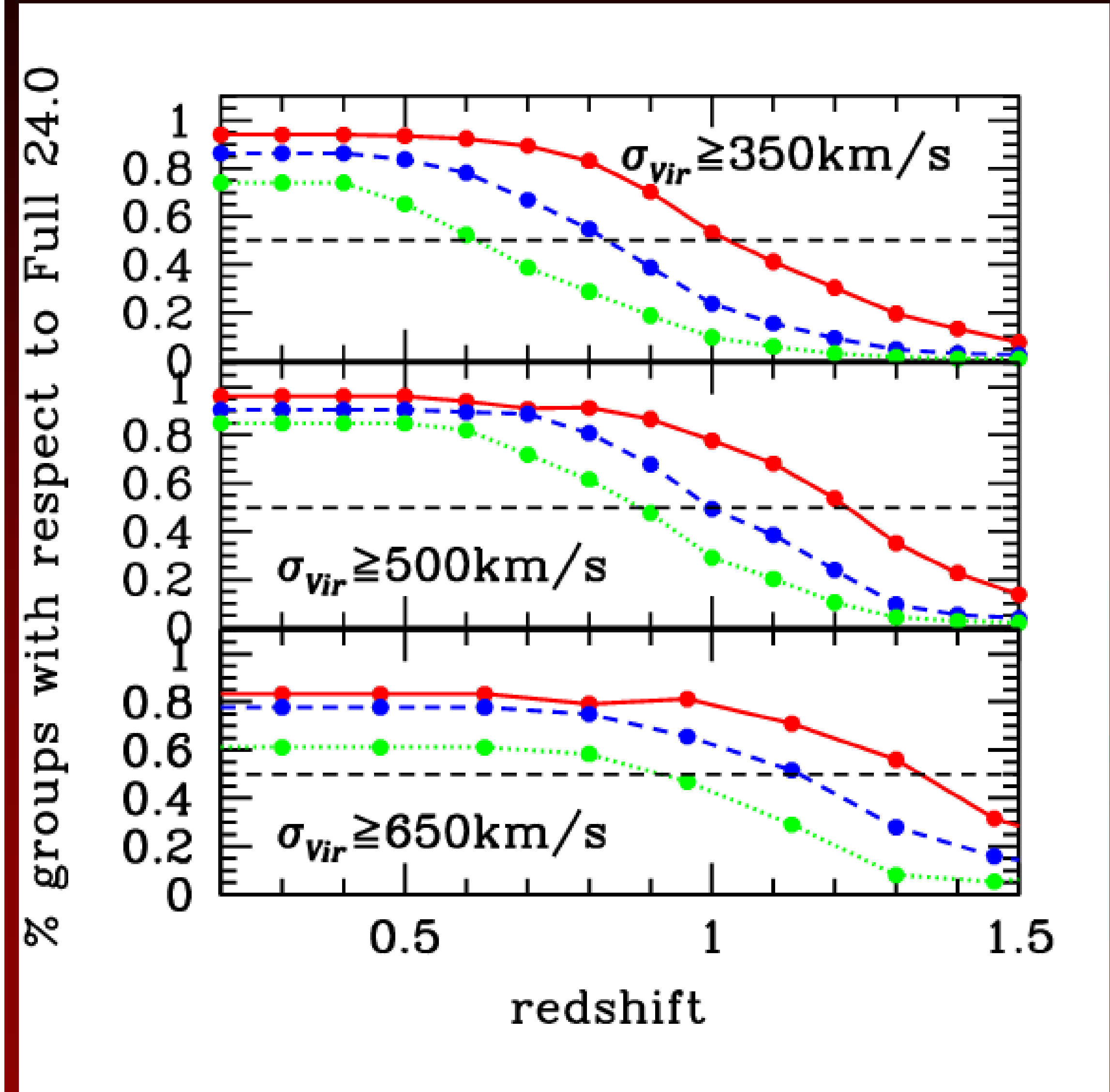
- **What is a Cluster ? Spherically collapsed isothermal sphere**

Observational Issues

Velocity-velocity calibration

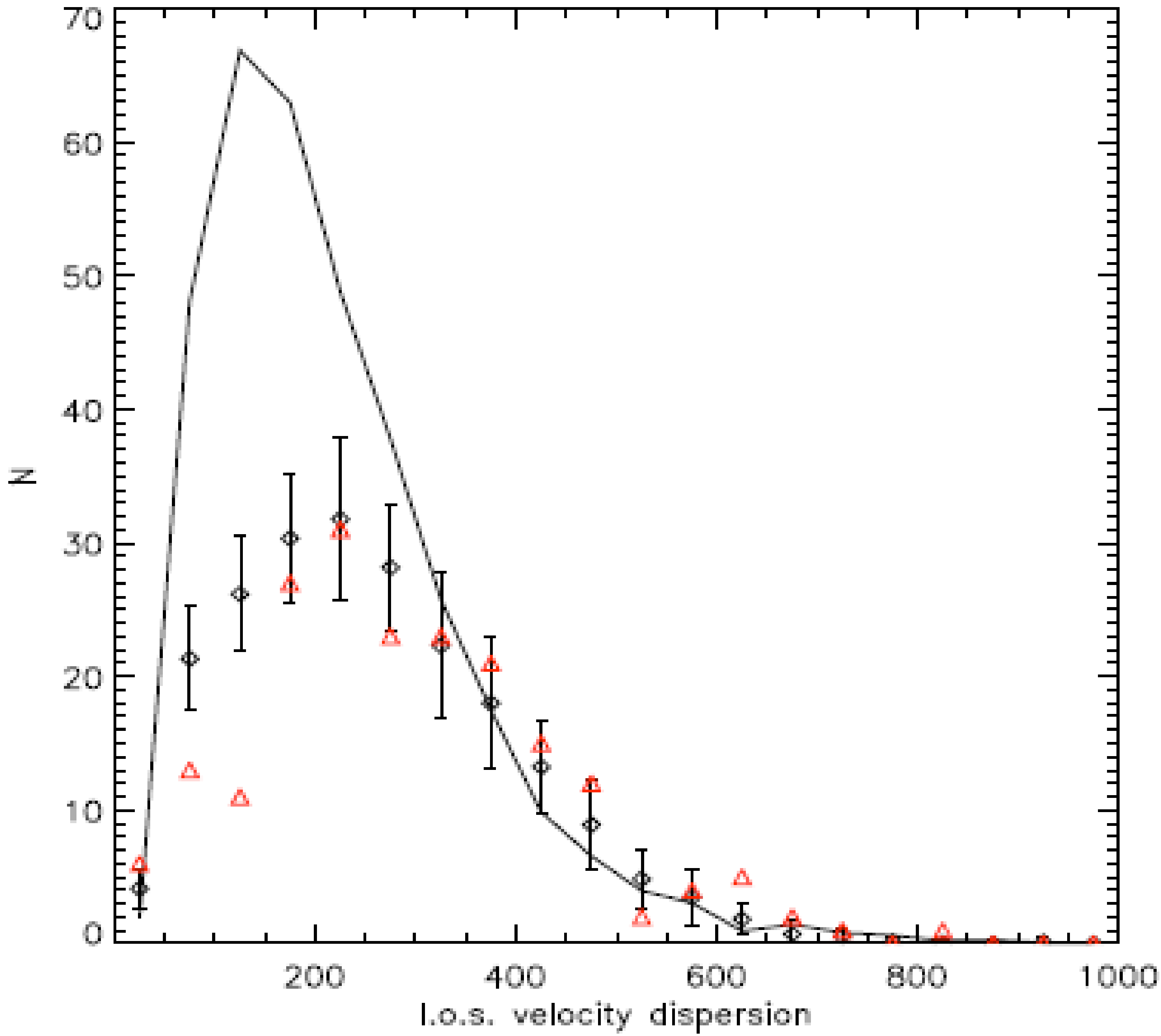
Selection function determination $\psi(\sigma)$

Velocity-velocity calibration



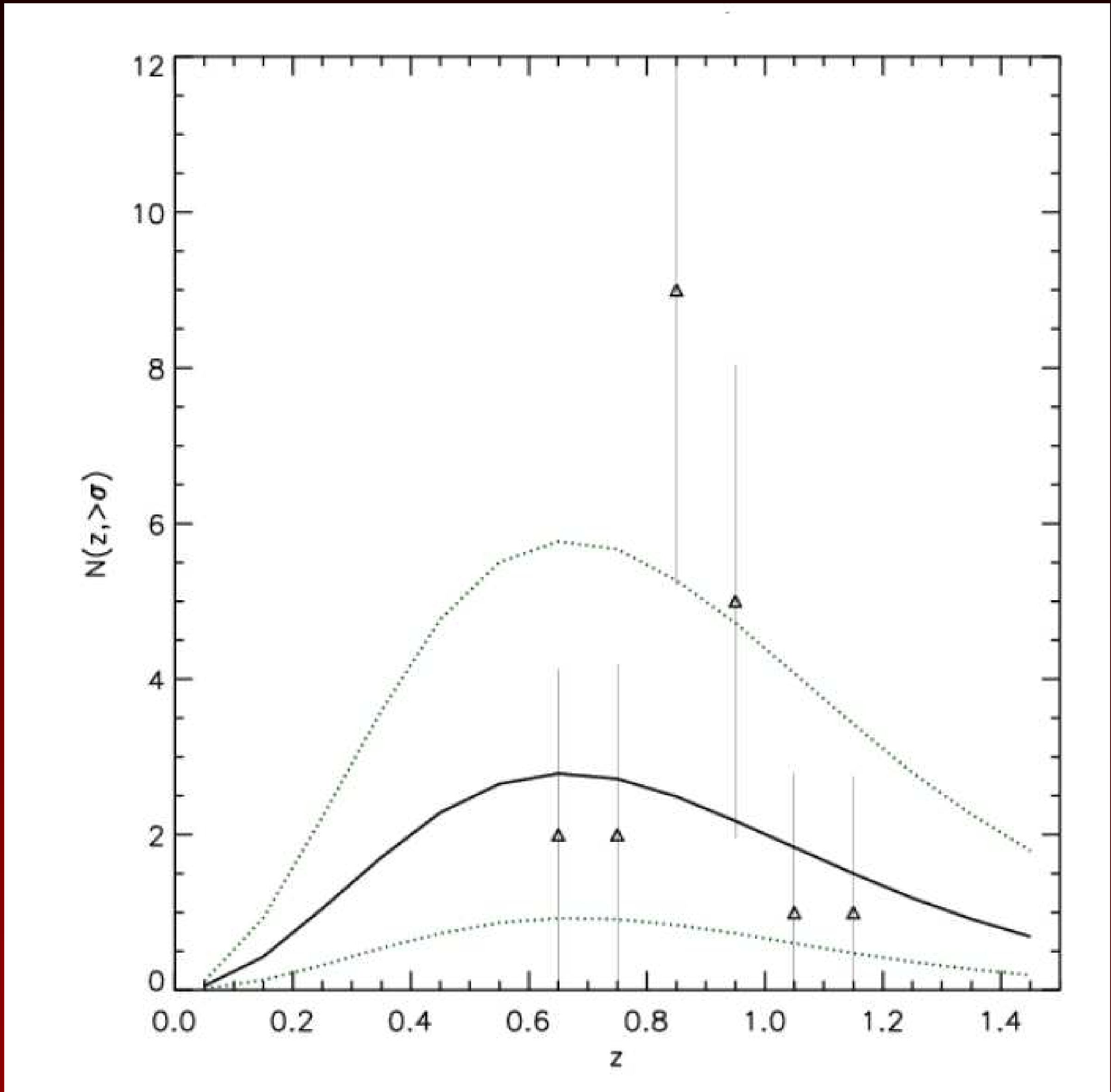
Millenium Simulation Mocks
mimiking the VVDS

$$\psi(\sigma \mid f = 0.33, I < 24)$$



N
l.o.s. velocity dispersion

VVDS + Deep2 Cluster Counts



Area

1.47 deg^2

Redshift range:

0.6<z<1.2

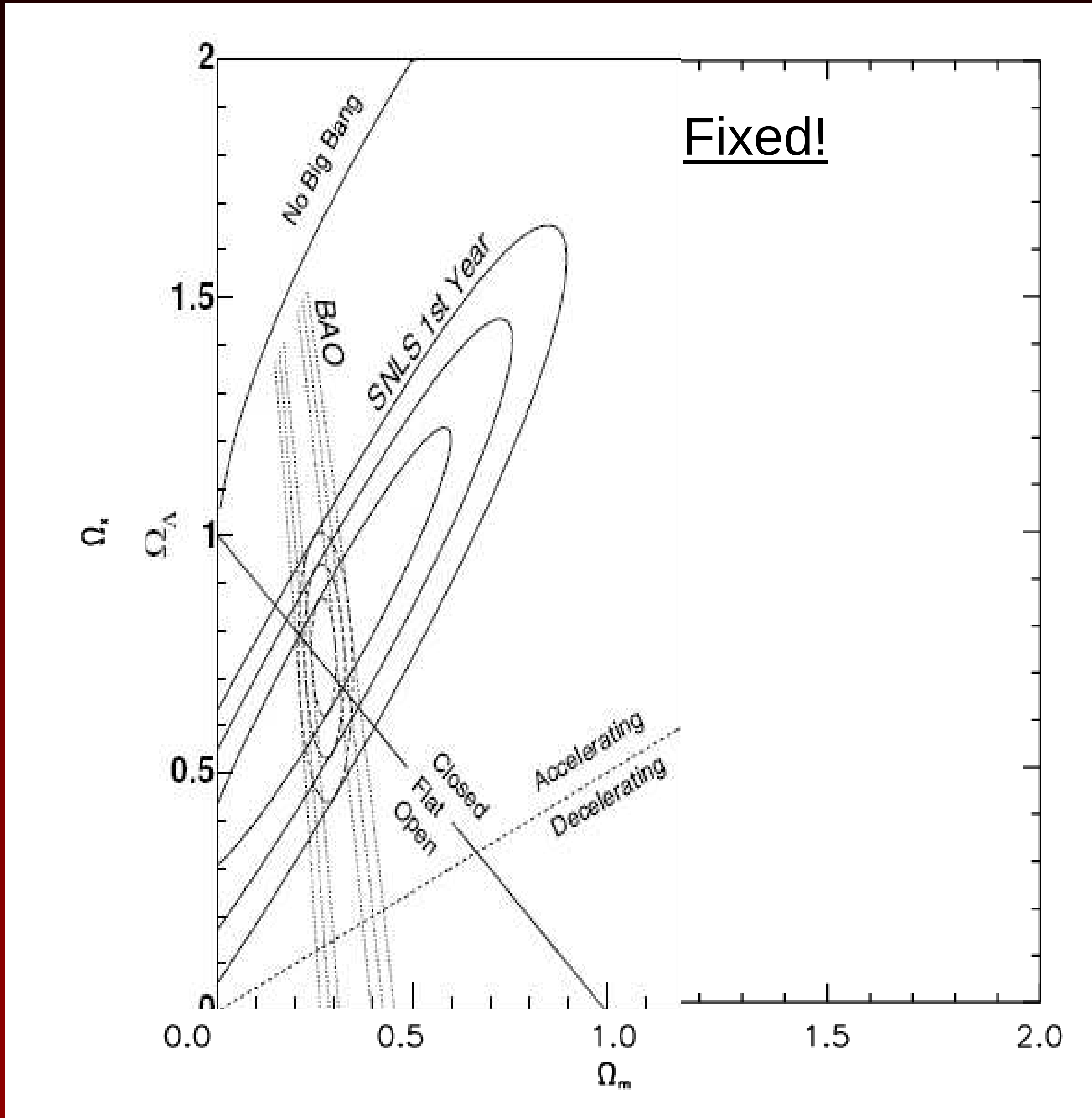
Error Budget

1.47 deg^2

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

1.47 deg^2

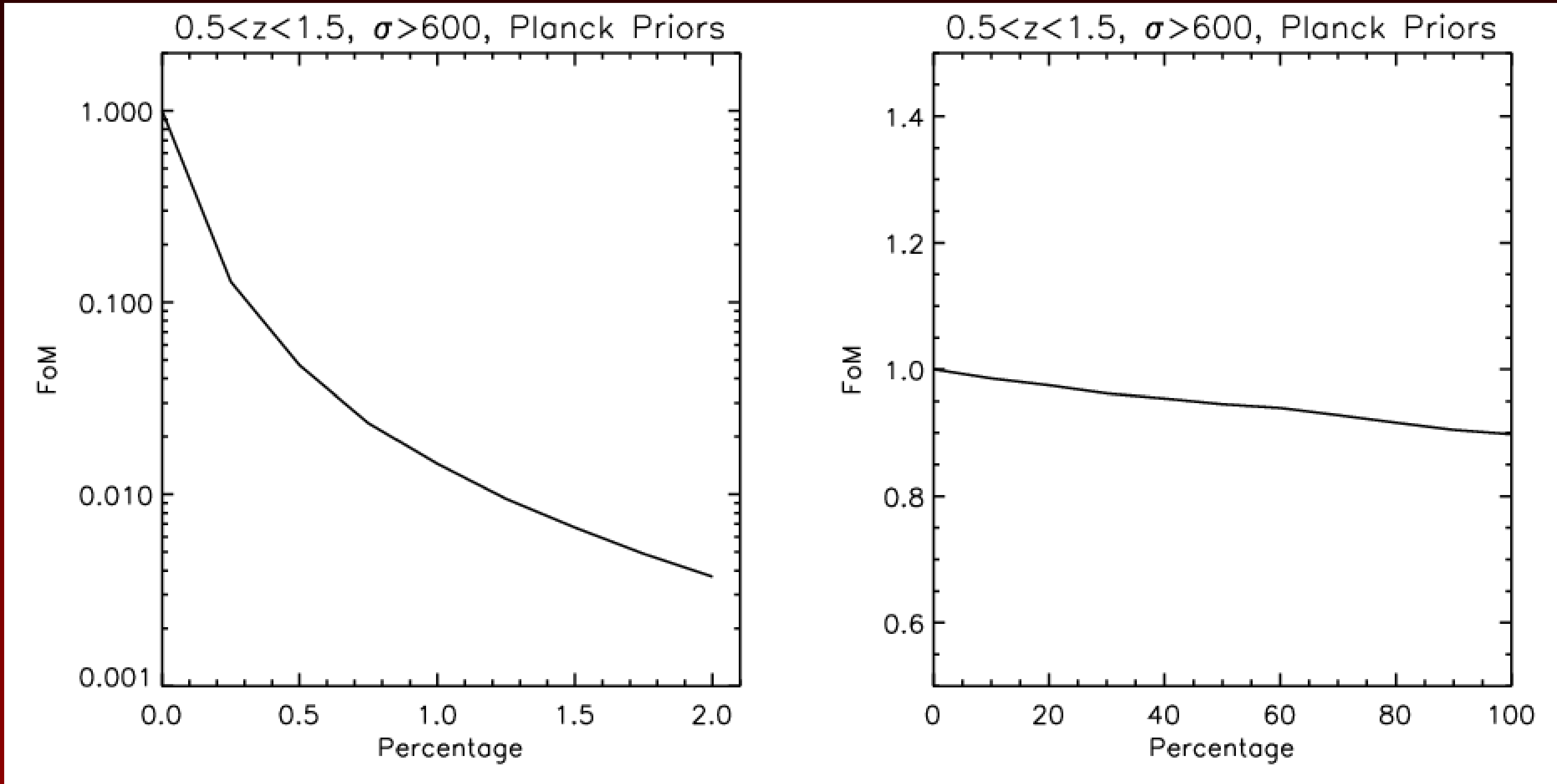
Velocity Threshold

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

Priors

- P(k) slope $n = 0.96 \pm 0.015$
- P(k) normalisation $\sigma_8 = 0.79 \pm 0.036$
- Flatness

Uncertainties in measuring Cluster Velocity Dispersion

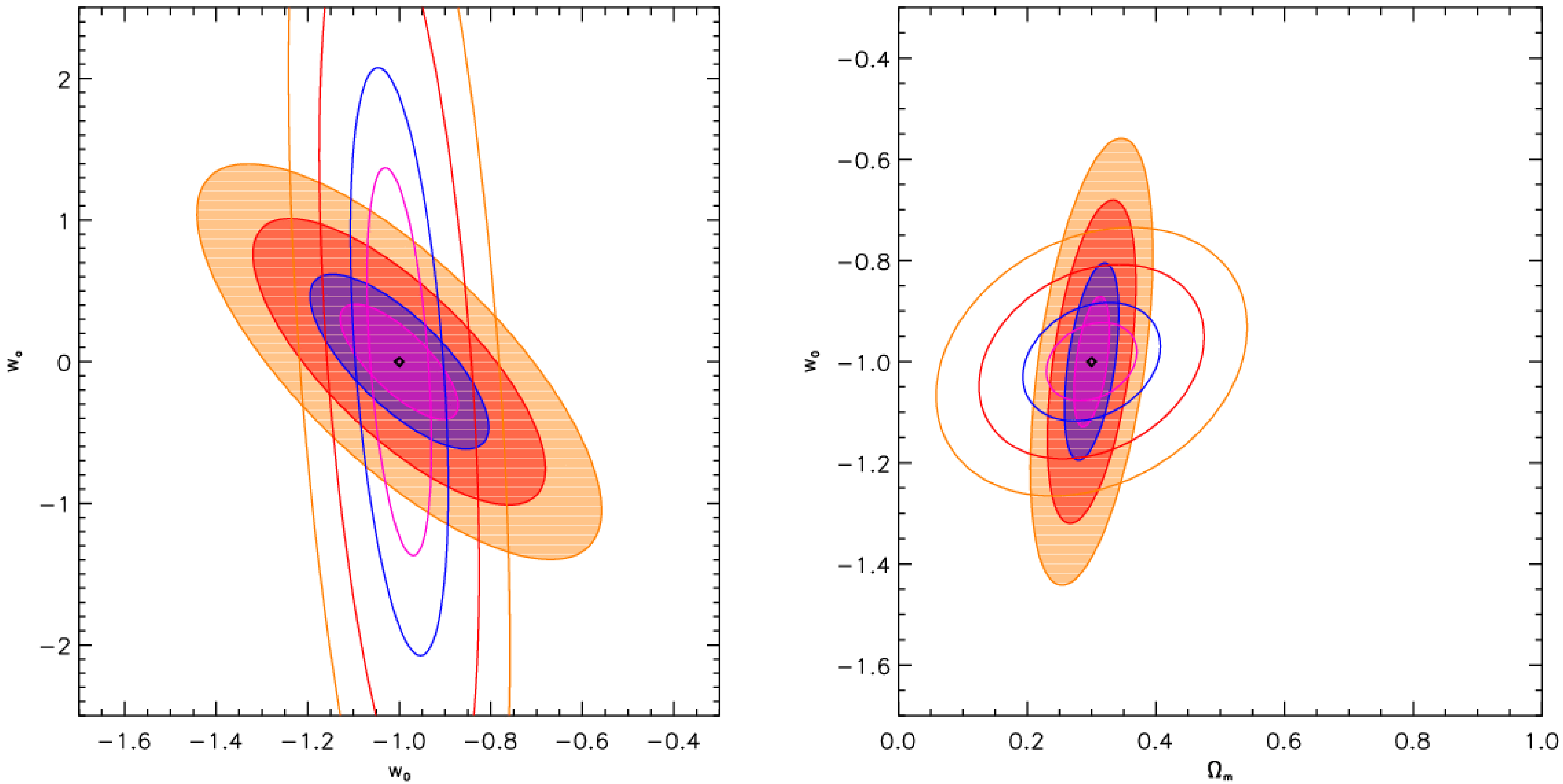


Systematic Offset

Random errors

Expected Constraints from a 10000deg^2 survey

1% systematics in both probes



Clusters:
Survey : 10000sq.deg, 0.5<z1.5,
Method : Plank priors, Integral counts

SNAP:
Survey : SNAP+300 Low-z
Method : Flatness

What is causing the accelerated Expansion of the Universe?

(A. Buzzi in preparation)

Assume only matter Ω_m=1

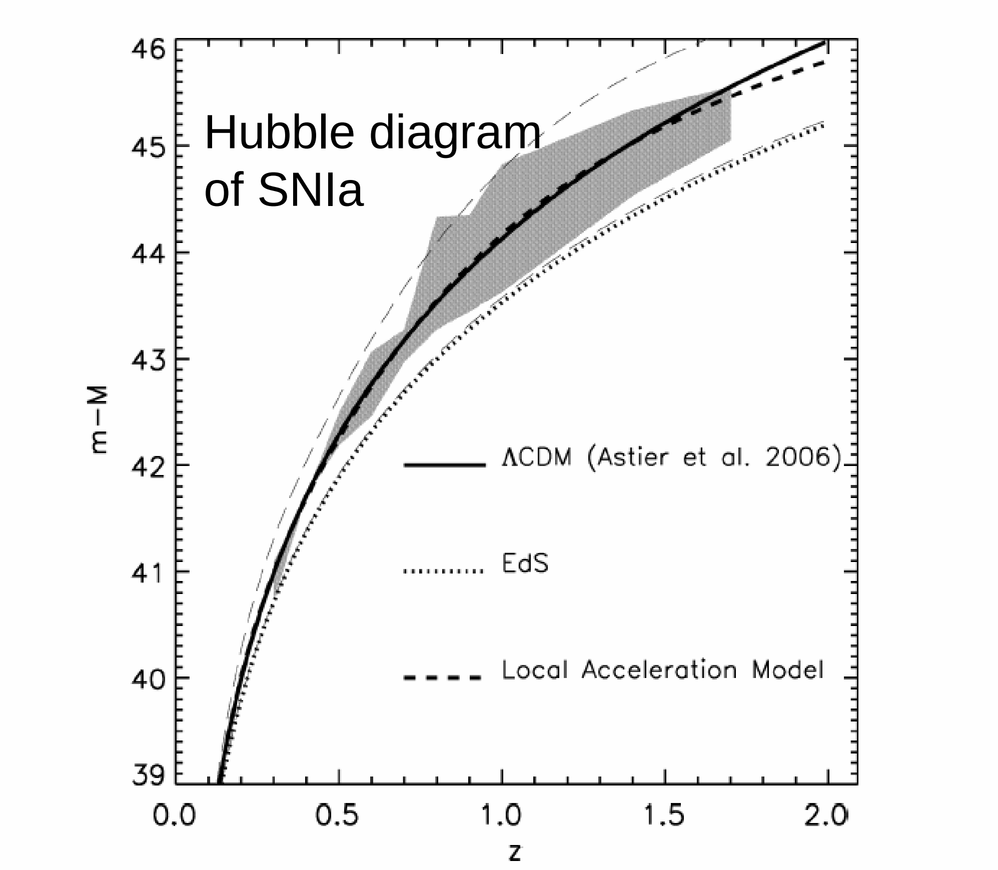
$$d_L = (1+z^o)\int_0^{z^o} \frac{c}{H(z)} dz$$

Work out the expession of $d_L(z)$ for non metric acceleration model

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

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

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



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

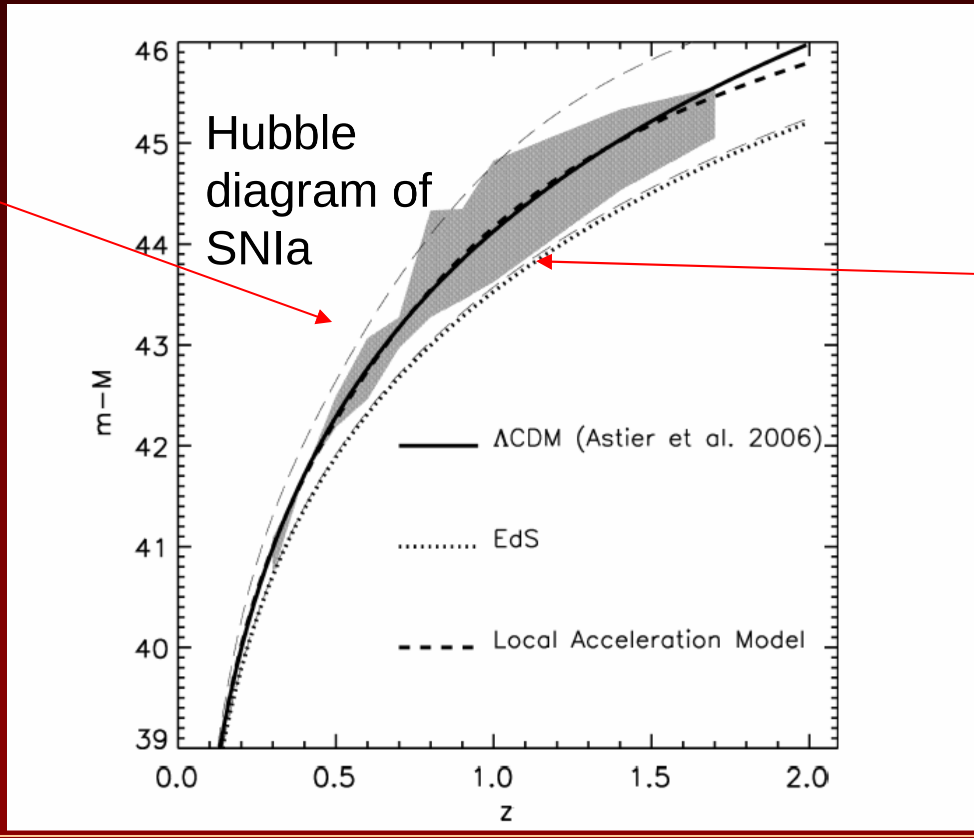
Prédictions

Existence d'une signature calculable et commune a tous les mécanisme non gravitationnels: Violation du Principe d'Équivalence

→ Interprétation physique de la dispersion du diagramme de Hubble

Less massive hosts

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



More massive hosts

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

On peut tester la nature de l'accélération avec une analyse environnemental des SNIa

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)

A new theory or a new component?

Finding Our Way in the Dark with Dynamics

Track record:

Inner solar system motions $\rightarrow$ General Relativity

Outer solar system motions $\rightarrow$ Neptune

Galaxy rotation curves $\rightarrow$ Dark Matter

Use galaxy dynamics on large scales to resolve the degeneracy

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 non-linear 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