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Invisible Universe International Conference

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in collaboration with K. Kainulainen, E. W. Kolb and S. Matarrese

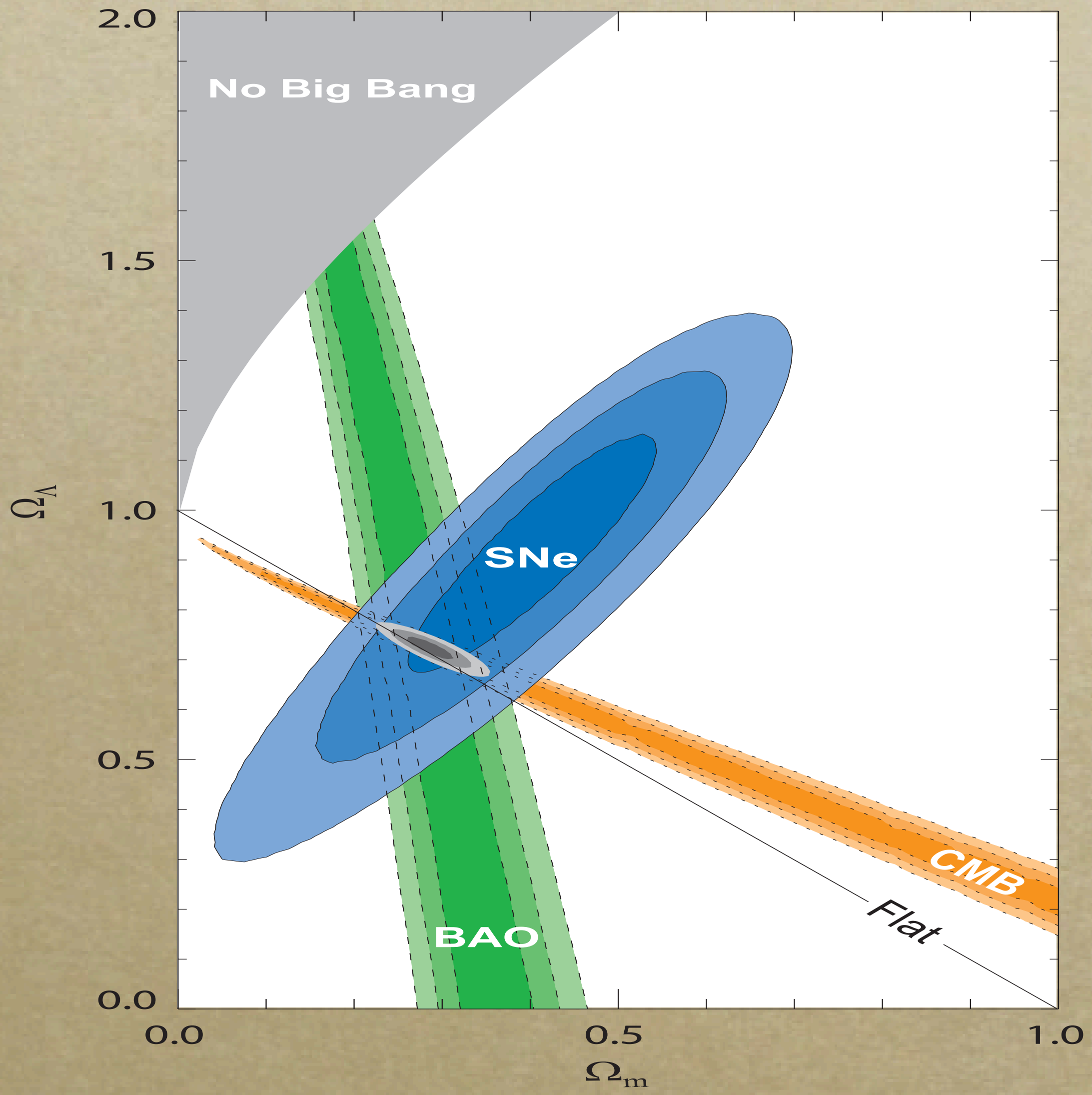
Impact of cosmic inhomogeneities on observations

K. Kainulainen and V. Marra,
Impact of cosmic inhomogeneities on observations,
arXiv:0906.3871 [astro-ph.CO].

K. Kainulainen and V. Marra,
A stochastic approach to cumulative weak lensing,
in preparation.

The cosmic concordance model

Kowalski et al. 08



$$\Omega_M \simeq 0.3$$
$$\Omega_{DE} \simeq 0.7$$
$$w_{DE} \simeq -1$$

successful, but…

- *coincidence problem*
- *origin problem*

Actual model or
just a fitting model?

Cosmological backgrounds

V. Marra, E. W. Kolb, S. Matarrese, arXiv:0901.4566 [astro-ph.CO].

- Global Background Solution (GBS) ⟶ $\rho_{GBS} = \langle \rho \rangle_H$, ${}^3\mathcal{R}_{GBS} = \langle {}^3\mathcal{R} \rangle_H$ + local equation of state

- Average Background Solution (ABS) [Buchert's background] ⟶ $a_H(t) \propto V_H(t)^{1/3}$; $\rho_{ABS} \neq \langle \rho \rangle_H$, ${}^3\mathcal{R}_{ABS} \neq \langle {}^3\mathcal{R} \rangle_H$

"averaged" equation of state: no local energy conditions

- Phenomenological Background Solution (PBS) ⟶ $d_L(z)$; $\rho_{PBS} \neq \langle \rho \rangle_H$, ${}^3\mathcal{R}_{PBS} \neq \langle {}^3\mathcal{R} \rangle_H$

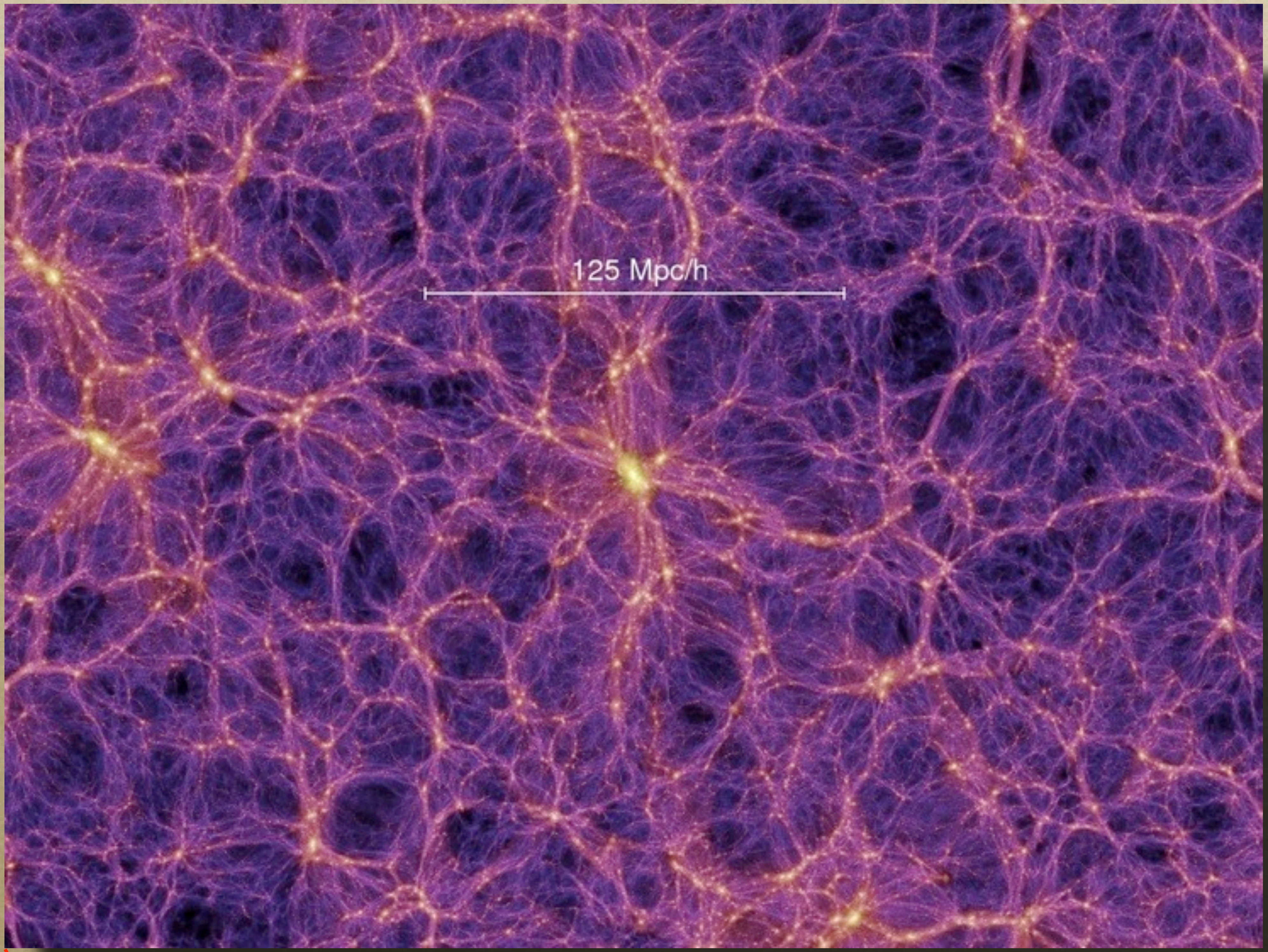
Cosmological backreactions

V. Marra, E. W. Kolb, S. Matarrese,
arXiv:0901.4566 [astro-ph.CO].

$[\langle \cdots \rangle,\ \mathrm{EoM}] \neq 0 \quad \Rightarrow \quad \mathrm{ABS} \neq \mathrm{GBS}$ $\longrightarrow$ strong backreaction

$[\langle \cdots \rangle,\ \mathrm{Obs}] \neq 0 \quad \Rightarrow \quad \mathrm{PBS} \neq \mathrm{GBS}$ $\longrightarrow$ weak backreaction

The Millennium Simulation Project



$15h^{-1}$ Mpc

Hubble-bubble meatball model

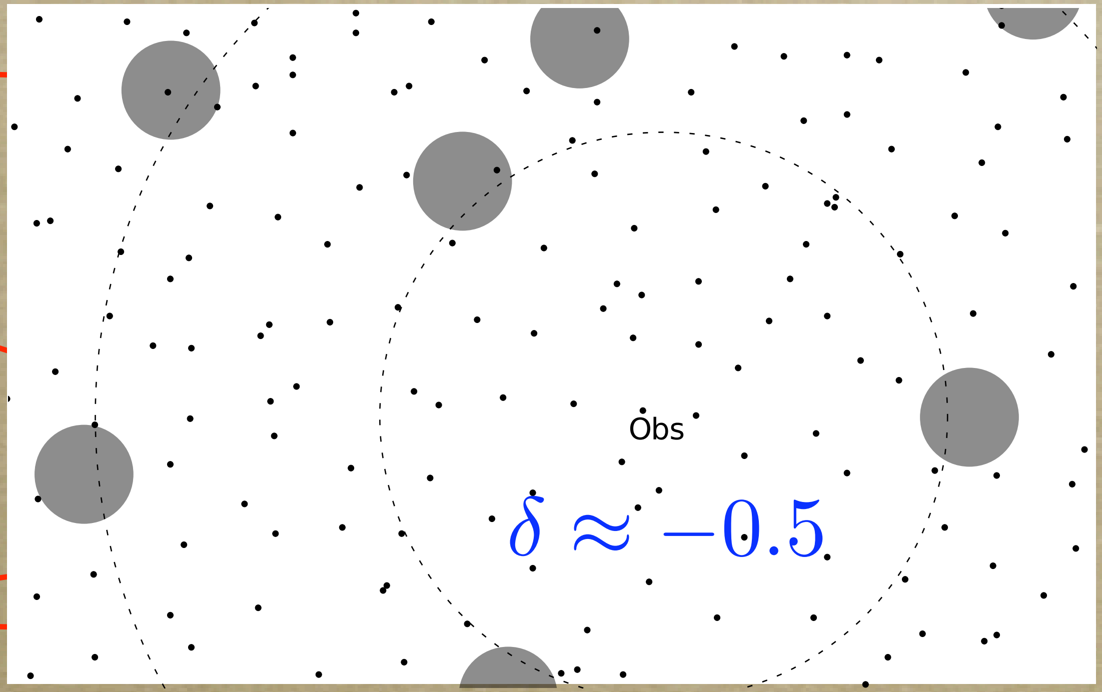
- GBS = EdS with: $h_\infty = 0.5$
- local observer with: $h = 0.58$

Quantity	Family A	Family B
fraction of tot. density	1/2	1/2
d_c	$100\,h^{-1}$ Mpc	$10\,h^{-1}$ Mpc
R_p	$10\,h^{-1}$ Mpc	$580\,h^{-1}$ kpc
M	$6.1 \cdot 10^{17} h^{-1} M_\odot$	$6.1 \cdot 10^{14} h^{-1} M_\odot$
density profile	Gaussian	SIS

Family A

Family B

LTB bubble



SNe observations

$L_{hom} \sim 100 h^{-1}\mathrm{Mpc}$

$L_{SNe} \ll L_{hom}$

$\longrightarrow$ Even if the f.a. is justified for the dynamics (GBS=ABS), it could not for the observations.

Zel'dovich 64, Bertotti 66, Dashevskii&Slysh 66, Kantowski 69, Dyer&Roeder 72

- small data samples
- selection effects

$\longrightarrow$ sizeable lensing effects

$\downarrow$

photons allowed to miss overdensities:
meatball model

Cumulative weak lensing

neglecting shear

$$G(r, r_s) = \frac{3H_\infty^2}{2c^2} \frac{r(r_s - r)}{r_s} \frac{1}{a(t(r))}$$

$$\Delta m(z) = 5 \log_{10}(1 - \kappa(z))$$

$$\kappa(z) = \int_0^{r_s(z)} dr\, G(r, r_s(z))\, \delta(r, t(r))$$

shift in distance modulus

effective lens convergence

unperturbed light path

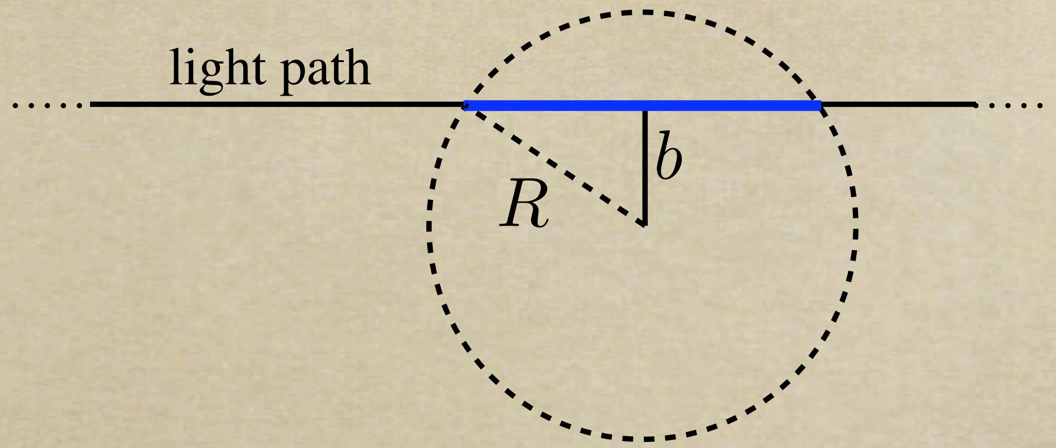
density contrast

$\delta > 0$ → magnification $\Delta m < 0$

$\delta < 0$ → demagnification $\Delta m > 0$

A stochastic method

$$\Gamma(b,t) = \int_b^{R(t)} \frac{2\,x\,dx}{\sqrt{x^2-b^2}}\varphi(x,t)$$



$\rho(x)/\bar{\rho}$ $\longrightarrow$ meatball

r_s $\longrightarrow$ N_S bin of widths Δr_i

R $\longrightarrow$ N_R bin of widths Δb_m

$\kappa_{1im} = G(r_i, r_s)\,\Gamma(b_m, t_i)$ $\longrightarrow$ convergence due to meatball in bin (i, m)

A stochastic method

$$\kappa(\{k_{im}\}) = \sum_{i=1}^{N_S} \sum_{m=1}^{N_R} \kappa_{1im} \big(k[\Delta N]_{im} - \Delta N_{im} \big)$$

convergence due
to one meatball

expected number
of meatballs in ΔV_{im}

$\Delta N_{im} = n_c \Delta V_{im}$

$\Delta V_{im} = 2\pi b_m \Delta b_m \Delta r_i$

Poisson random variable
of parameter ΔN_{im}

A stochastic method

$$\kappa(\{k_{im}\}) = \sum_{i=1}^{N_S} \sum_{m=1}^{N_R} \kappa_{1im} \left(\frac{k[N_O \Delta N]_{im}}{N_O} - \Delta N_{im} \right)$$

convergence PDF is generated by the configurations $\{k_{im}\}$

convergence due to one meatball

observations at redshift z

expected number of meatballs in ΔV_{im}

$\Delta N_{im} = n_c \Delta V_{im}$

$\Delta V_{im} = 2\pi b_m \Delta b_m \Delta r_i$

Poisson random variable of parameter $N_O \Delta N_{im}$

- expected convergence zero: photons conservation
- PDF approaches δ-function at $\kappa = 0$ for $N_O \to \infty$
- **FAST!!** PDF for N_O-samples in few minutes: just to generate Poisson random numbers
- Only weak-lensing approximation: $\lesssim 5\%$ of error (worst case)

Resumming Poisson variables

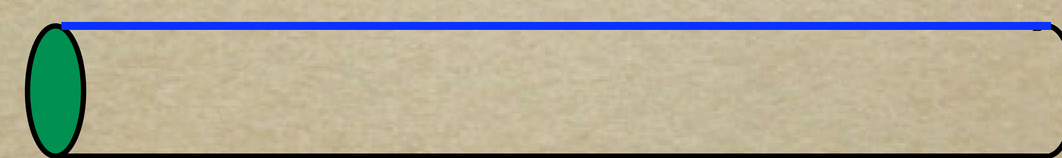
Poisson variable
of parameter $N_O N$

$$\kappa(k) = \kappa_E(z) \left(1 - \frac{k[N_O N]}{N_O N}\right)$$

convergence for
empty beam

$$N = n_c \cdot \underline{r_s(z)\, E} \cdot \underline{\pi \bar{R}^2 Q_\varphi^2}$$

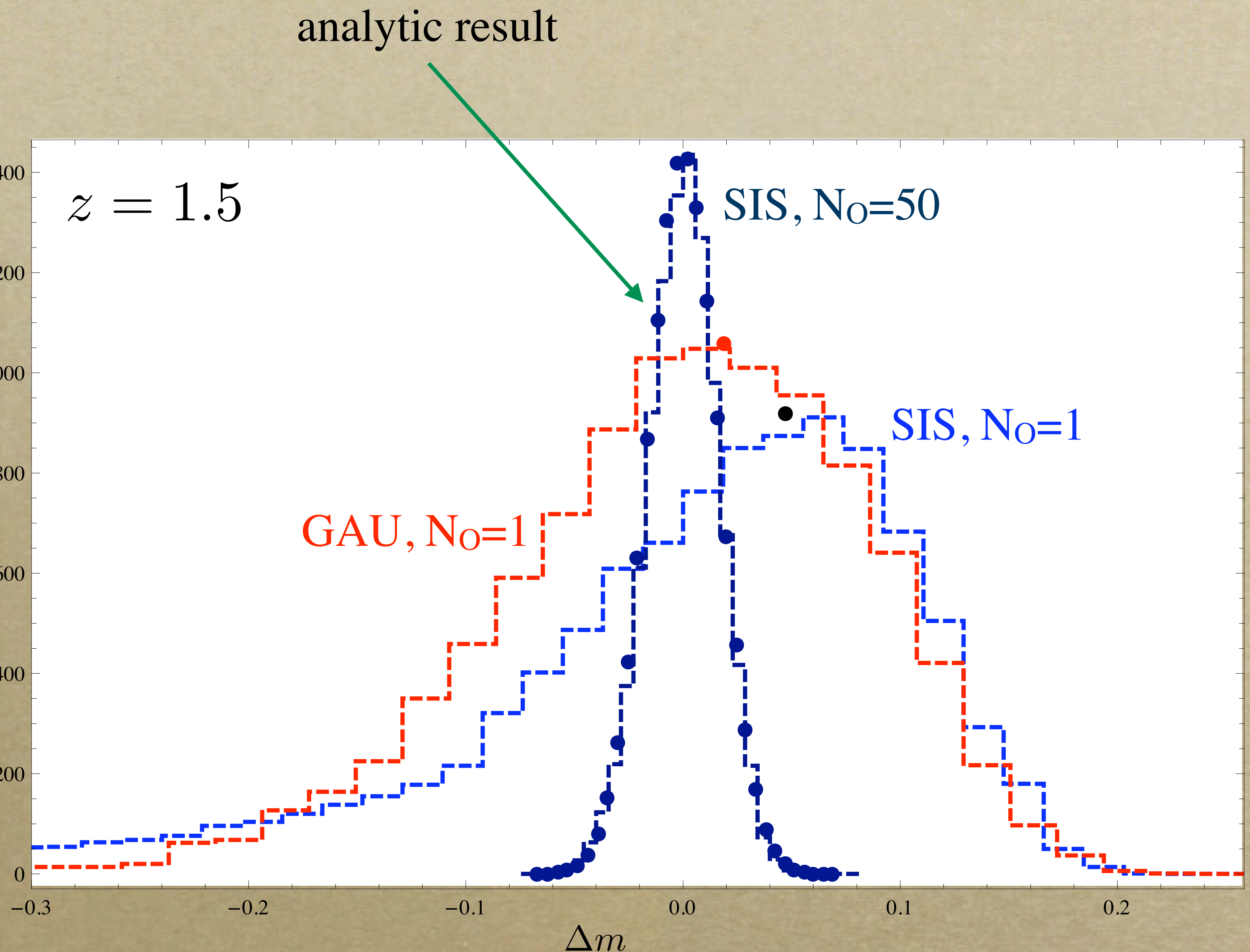
expected
hits in:



- analytic result, not a fit: well approximates the PDF for $N_O N \gtrsim 5$
- mode of the PDF for N_O-samples: $\kappa(\hat{k}) = \kappa_E(z) \left(1 - \frac{\lfloor N_O N \rfloor}{N_O N}\right)$

easy way to estimate
lensing bias for given
cosmological parameters

PDF-example



ΛCDM with

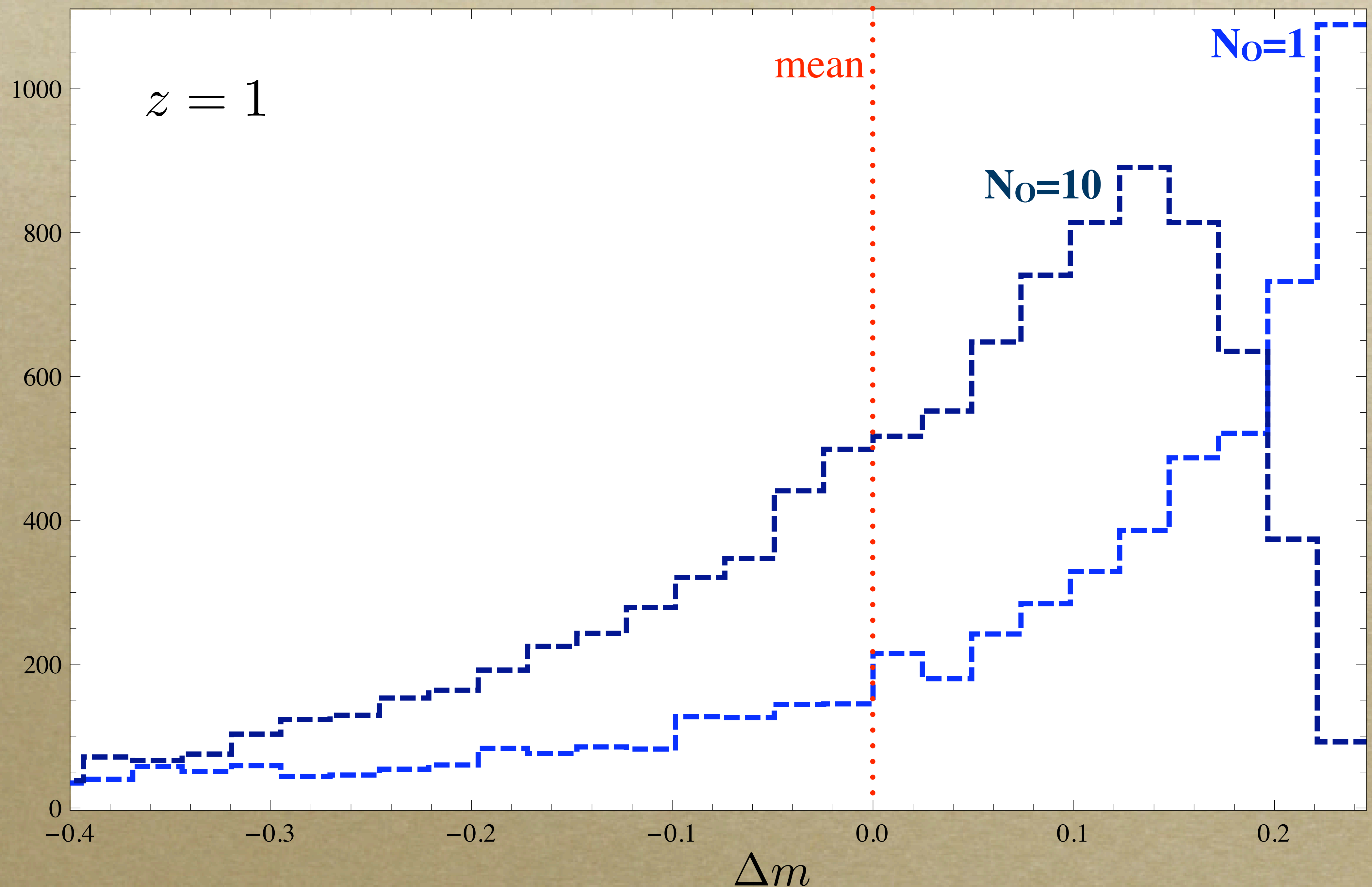
$d_c = 2\text{Mpc}$

$R = 200\text{kpc}$

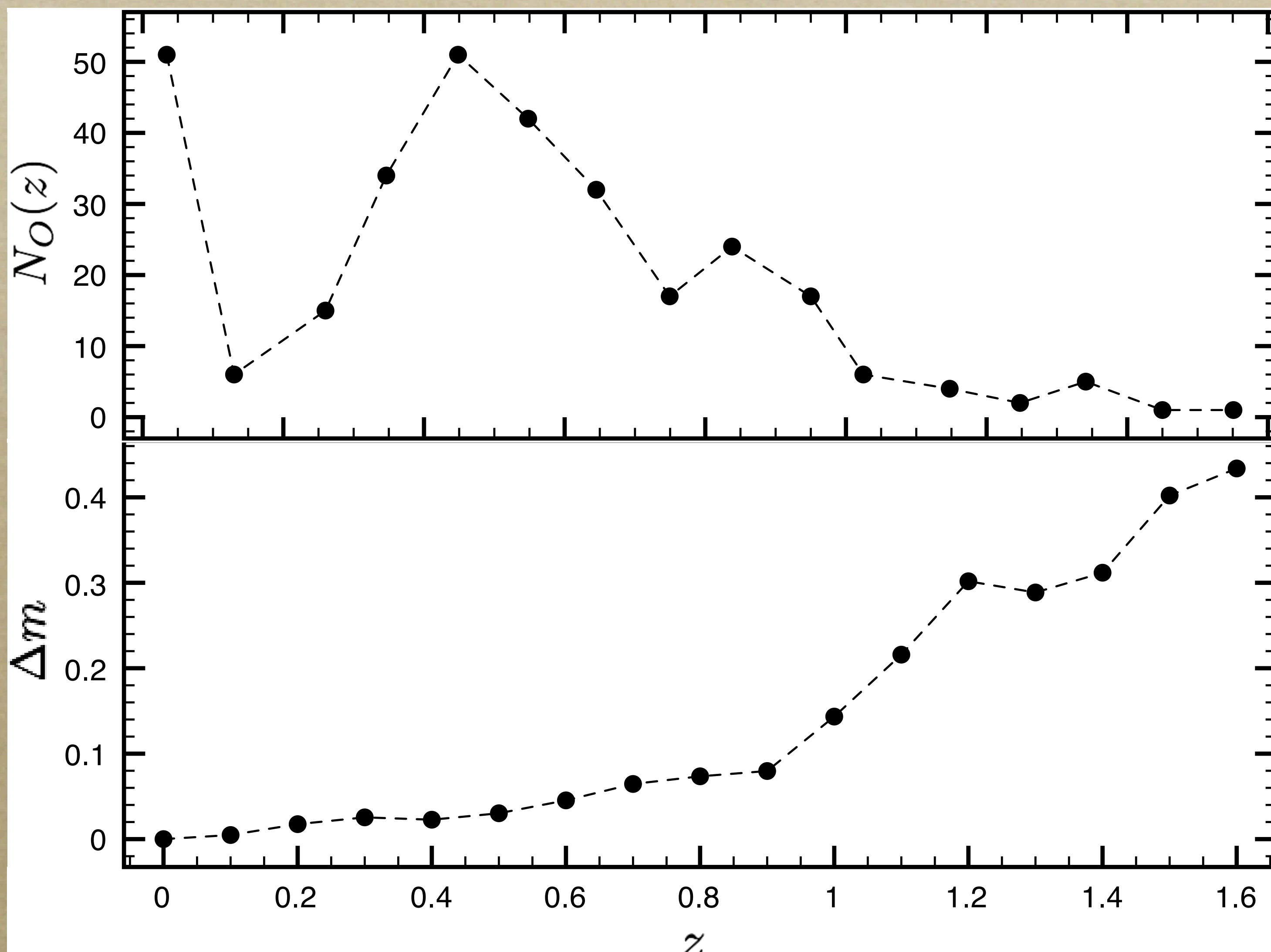
[parameters of Holz&Wald 98 and Holz&Linder 05]

code available soon!

PDF for meatball model



Lensing bias



the 307 SNe of Union Catalogue of *Kowalski et al. 08* binned with $\Delta z = 0.1$

sizeable shift in distance modulus for the meatball model

Let us turn to the second source of $[\langle \cdots \rangle, \mathrm{Obs}] \neq 0$: **local Hubble bubble**

Local Hubble bubble

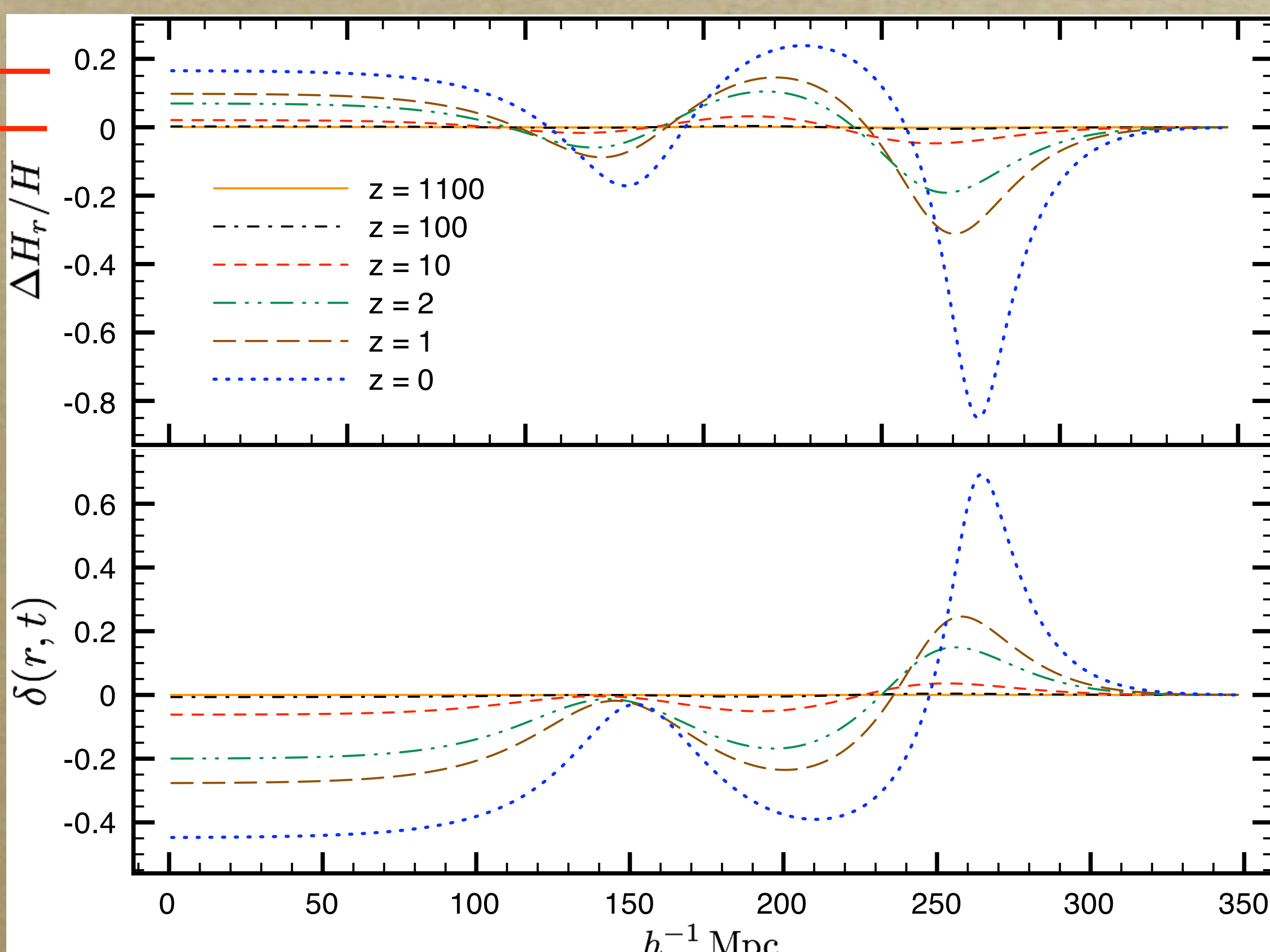
$$\frac{\dot{a}^2(r,t)}{a^2(r,t)} = \frac{8\pi G}{3}\,\hat{\rho}(r,t) - \frac{c^2 k(r)}{a^2(r,t)}$$

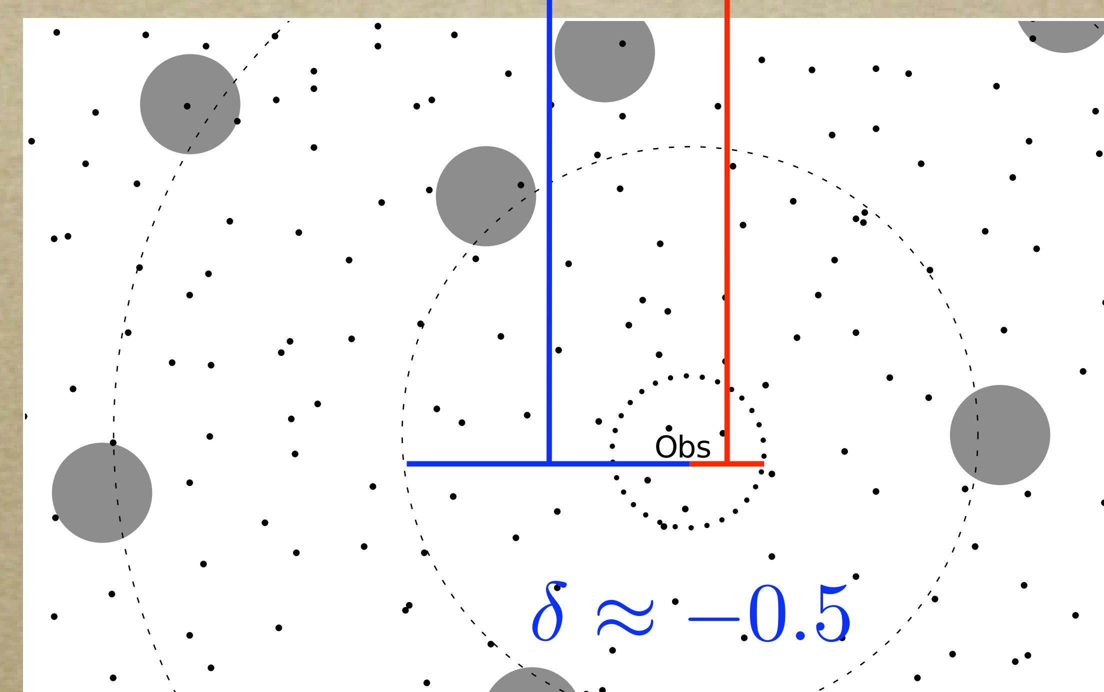
LTB metric matched to EdS/GBS

$d_{obs} \lesssim 15h^{-1}$ Mpc

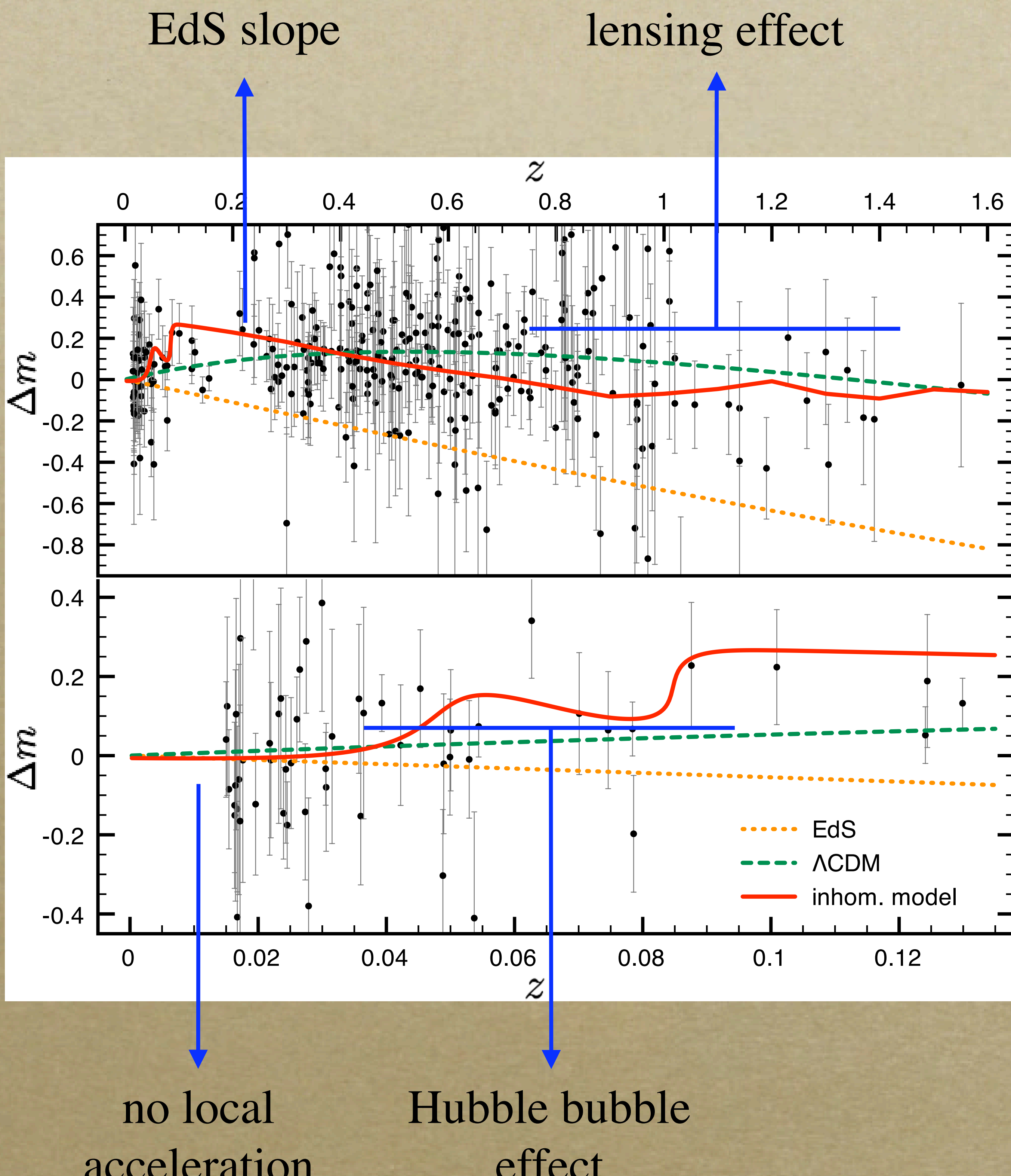
"spatial" ΔH mimics "temporal" ΔH

$100h^{-1}$ Mpc





Results



Model	χ^2
ΛCDM	312
ΛCDM + meatballs	323
EdS	608
EdS + H. bubble	440
EdS + H. bubble + meatballs	396

Different effects of inhomogeneities pull into the same direction, making the PBS depart from the GBS

THANKS