Dark Cosmology Centre

Cosmic variance of the local Hubble flow

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NBIA-APCTP Copenhagen, 19.08.2014

Outline

1. Observational constraints on H_0 from SNe Ia and CMB
2. Cosmic variance of the local Hubble flow
   - analytic approach
   - cosmological simulations
4. Results from large-scale simulations: Jubilee and Big MultiDark

collaborators: Alexander Knebe, David Rapetti, Steffen Hess, Stefan Gottloeber, Ilian Iliev, Gustavo Yepes

3. Cosmic variance and the difference between H_0 from SNe Ia and CMB
4. Is there a tension between Planck and the local Universe ?

5. Gravitational redshift from large scale structures
6. Effect of the gravitational redshift on cosmological parameters from SNe Ia

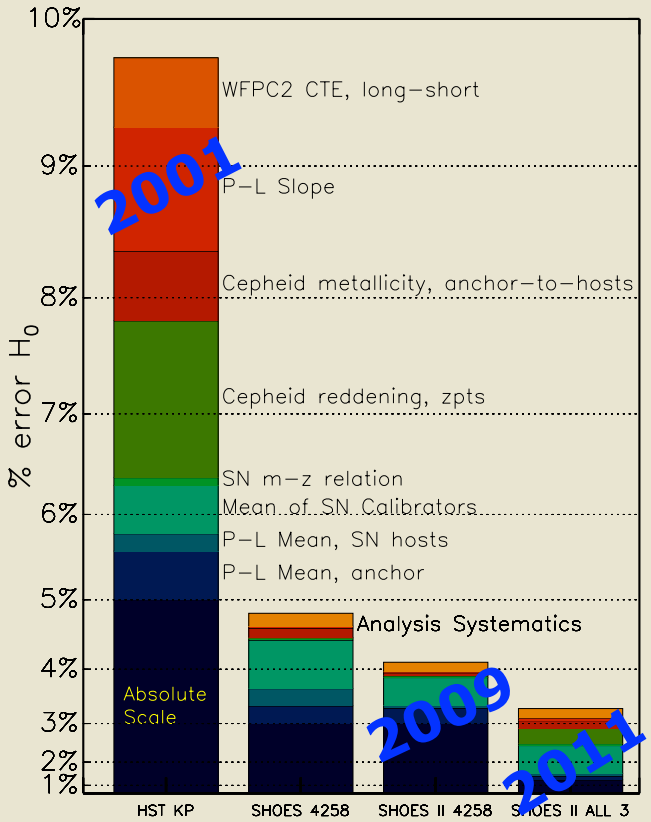
collaborators: Jophiel Nyman Wiis, Tamara Davis

3% solution: SNe Ia

$$H_0 = 73.8 \pm 2.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

- 140 SNe Ia at 0.023<z<0.10
- distance calibration: LMC, MW parallaxes and NGC4258 maser
- ~600 Cepheids in 8 SN Ia hosts

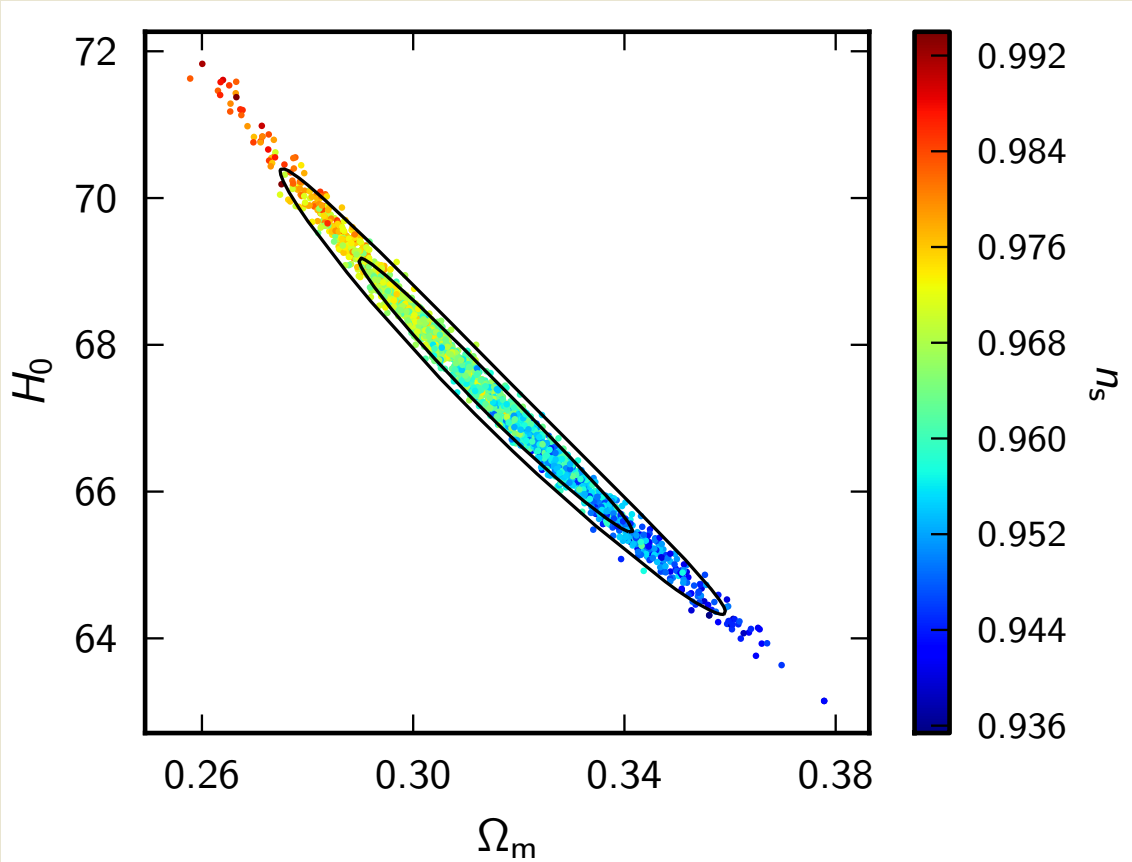
Riess et al (2011)



1% ?

$$H_0 = (67.3 \pm 1.2)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

(assuming the standard flat 6-parameter cosmology)



Planck Collaboration (2014)

H_0 from CMB and Sne Ia: comparison

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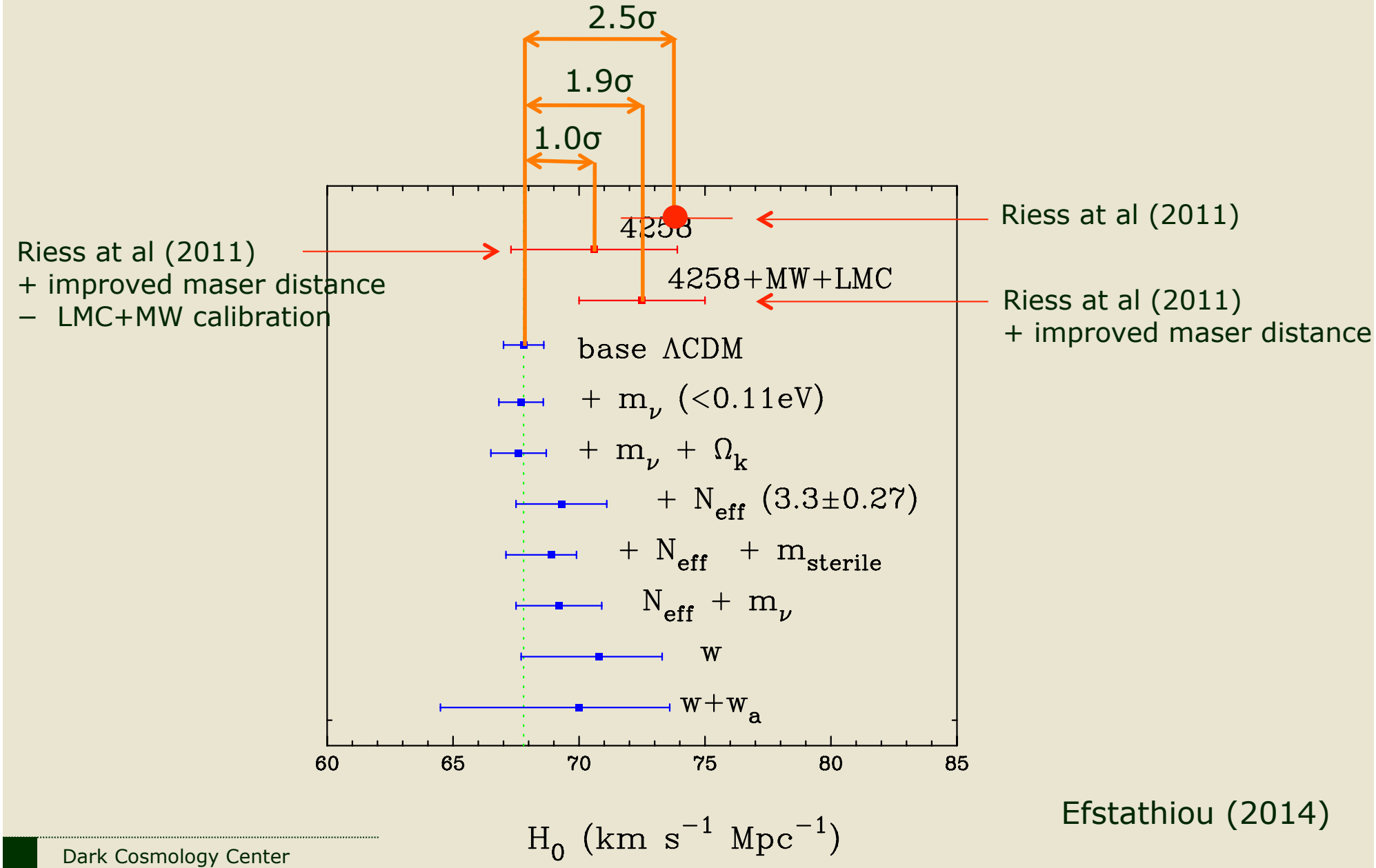

Efstathiou (2014)

Inhomogeneous universe

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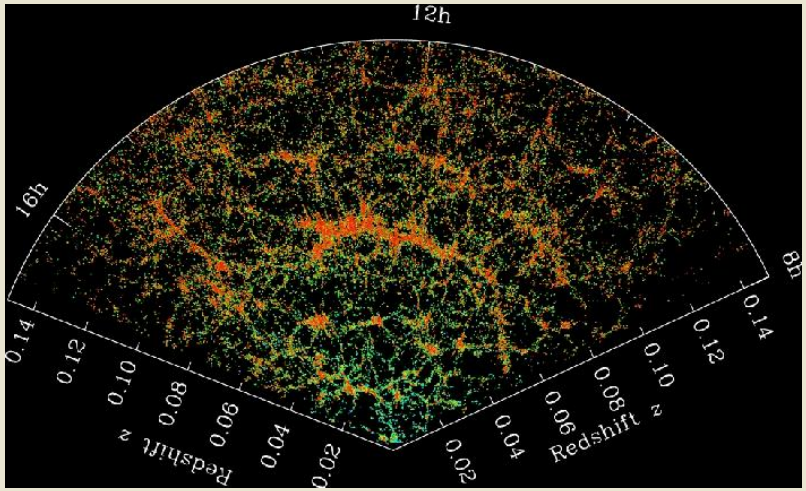
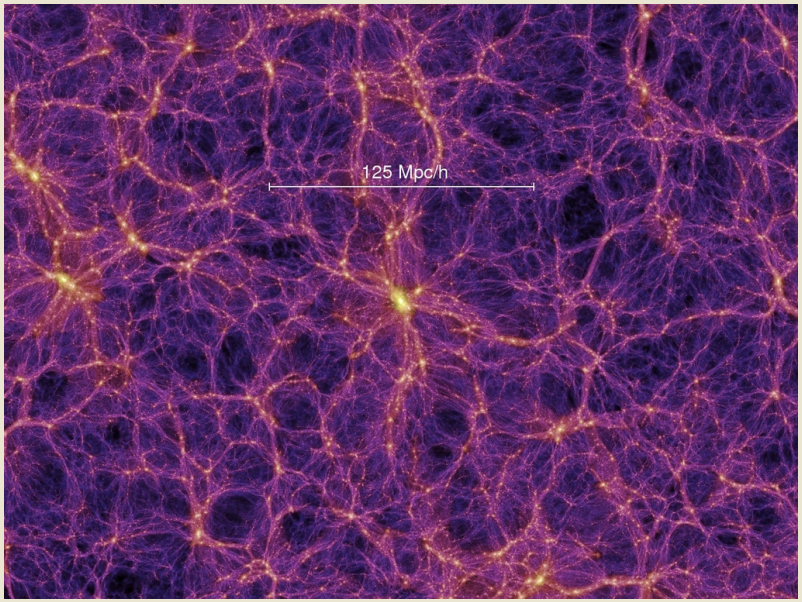


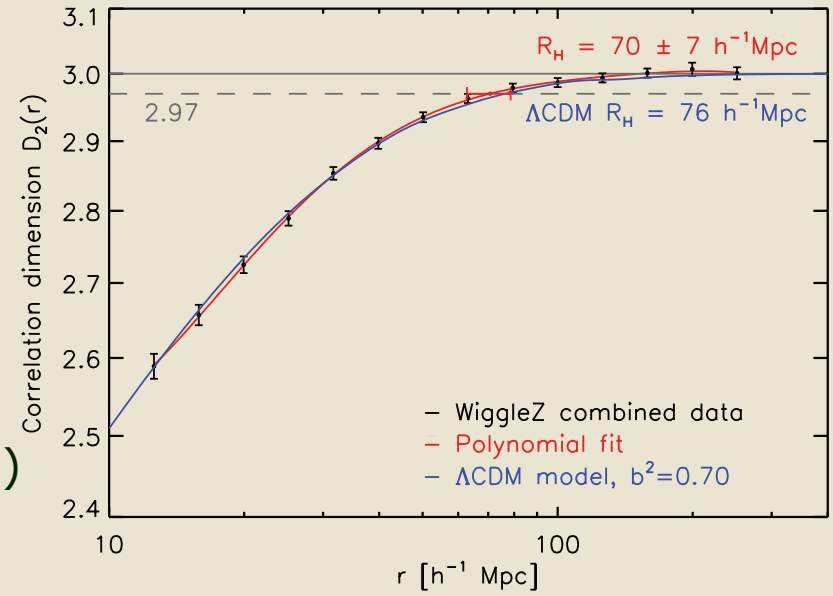
SDSS

Millennium Simulation



scale of inhomogeneities: ~100 Mpc/h

median distance of SNe Ia: (75-100) Mpc/h



Scrimgeour et al (2012)

Local Hubble flow

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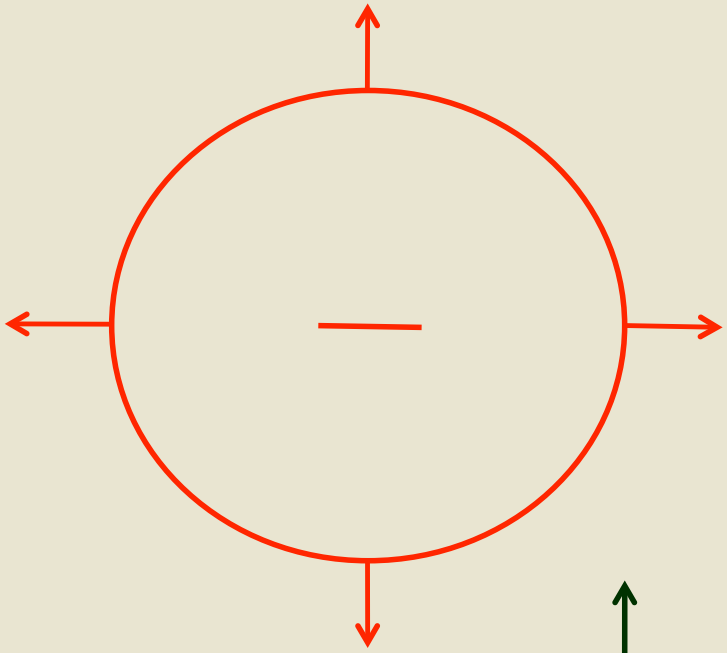

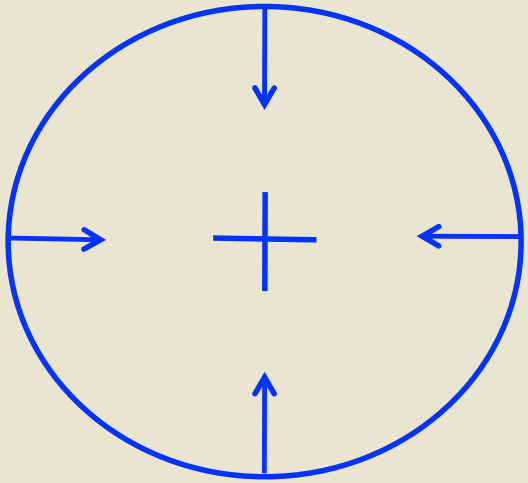

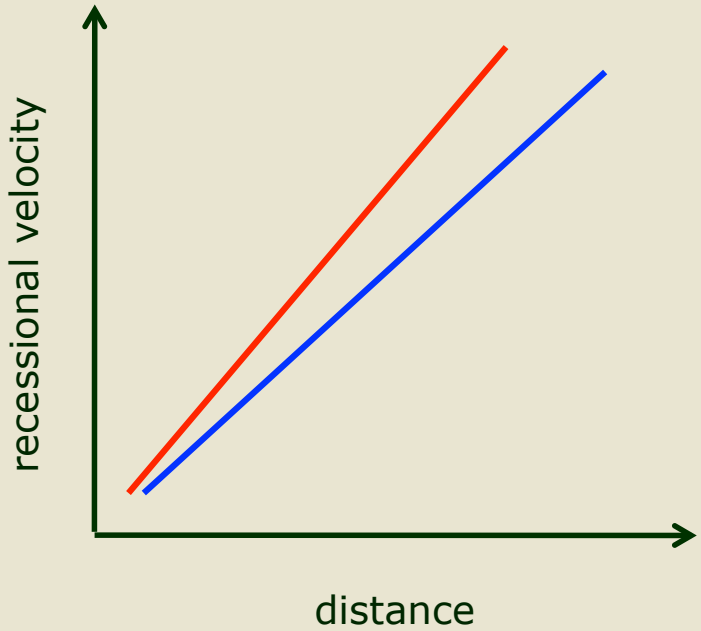

Linear calculation of $\delta H_0/H_0$

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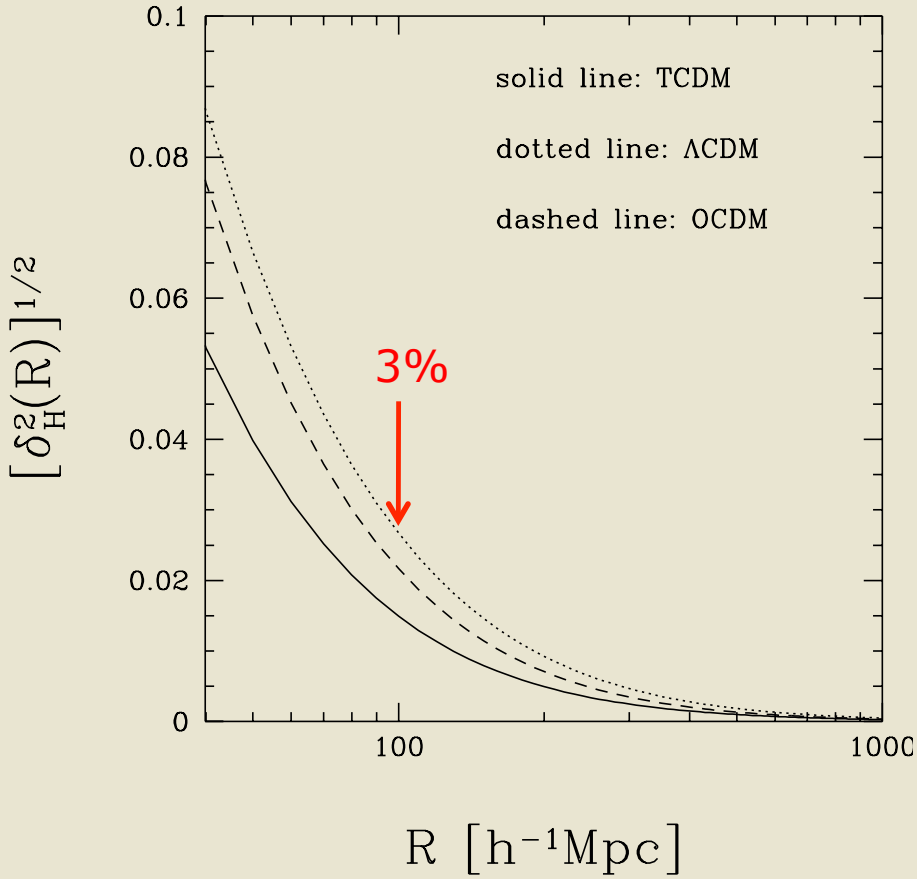
$$\delta_H(x)^R = \int d^3y \, \frac{v(y)}{H_0} \cdot \frac{y-x}{|y-x|^2} \, W(y-x)$$

$$v_k = \frac{\Omega_0^{0.60} H_0}{ik} \, \delta_k \hat{k}$$



Wang, Spergel & Turner (1998)

(weakly non)Linear + redshift distribution of SNe Ia

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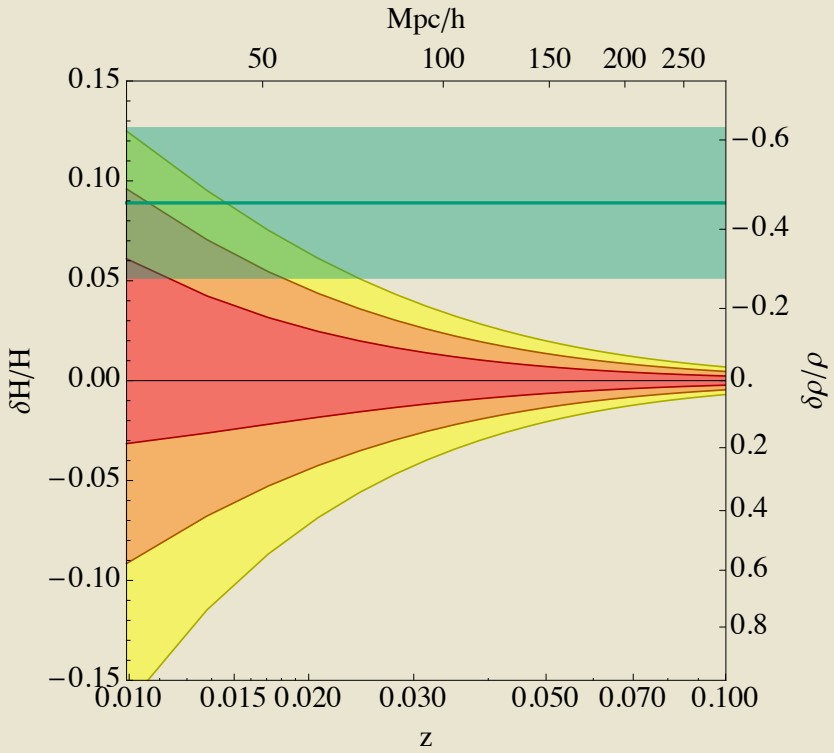
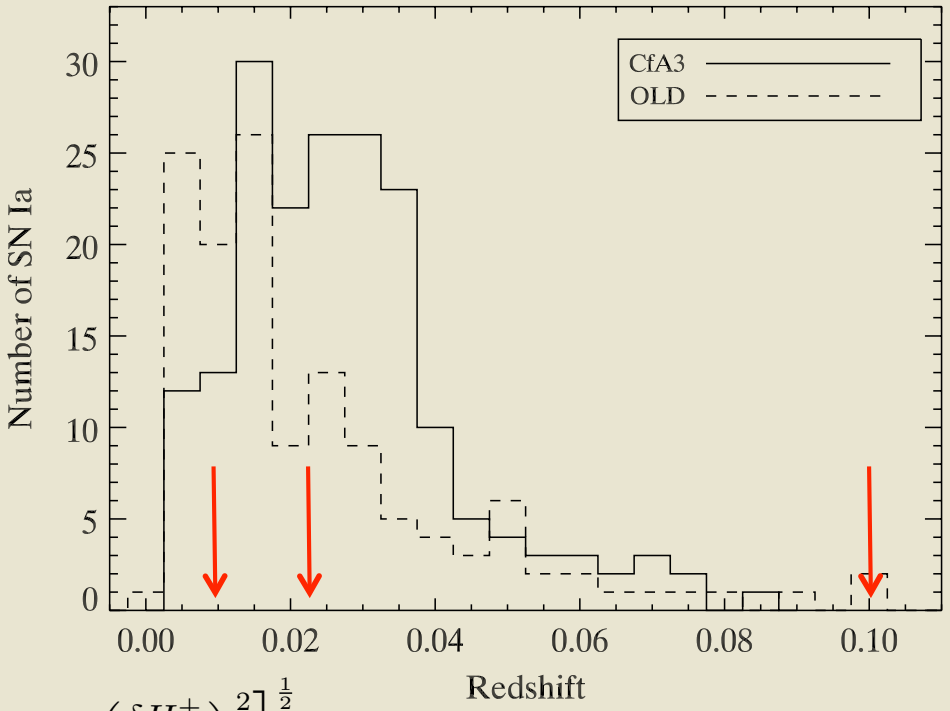




Marra et al (2013)

$$\sigma^{\pm}_{H_0} = \left[\int_{z_{\rm min}}^{z_{\rm max}} {\rm d}z \, W_{\rm SN}(z) \left(\frac{\delta H^{\pm}}{H} \right)^2 \right]^{\frac{1}{2}}$$

Hicken et al (2009)

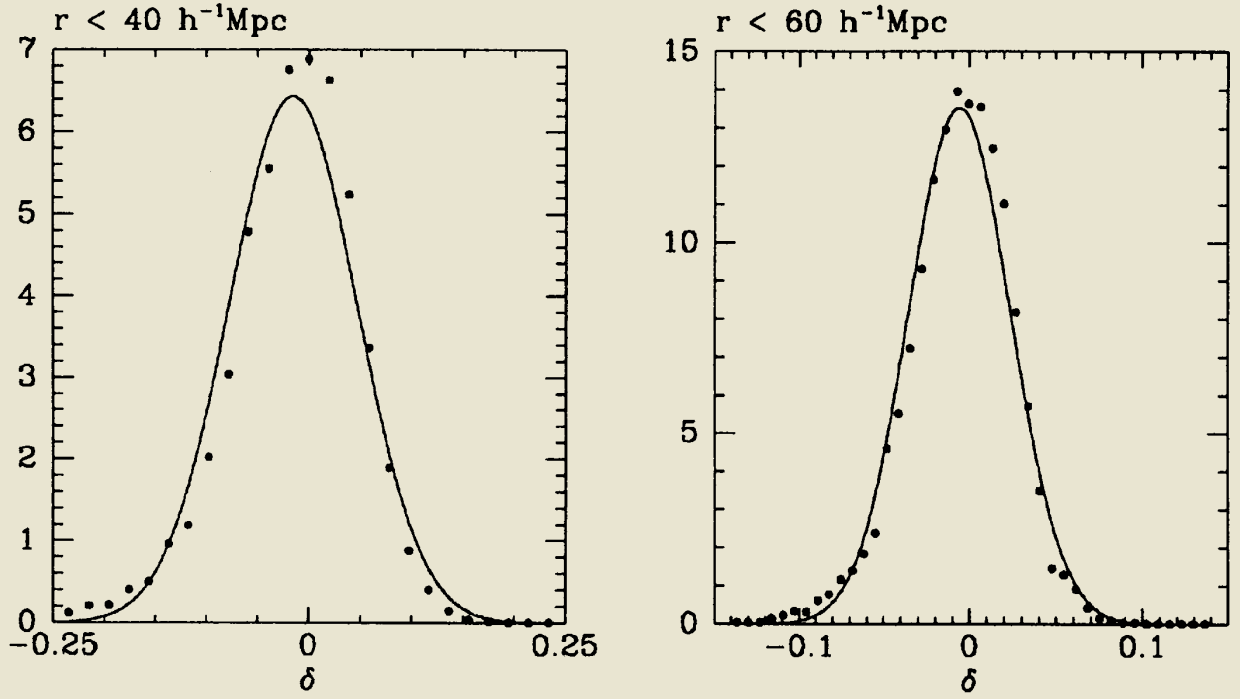
Case	Density Contrast Distribution	$z_{\rm min}$	$\sigma^{+}_{H_0}$	$\sigma^{-}_{H_0}$	$\delta H^{+}_0 \left(\frac{\rm km/s}{\rm Mpc}\right)$	Adding errors linearly	Adding errors in quadrature
I	$p_{\rm gau}$ of Eq. (3)	0.010	2.1%	2.1%	1.58	$\Delta H = 1.6\sigma$	$\Delta H = 2.1\sigma$
II	$p_{\rm logn}$ of Eq. (4)	0.010	2.4%	1.7%	1.79	$\Delta H = 1.5\sigma$	$\Delta H = 2.1\sigma$
III	$p_{\rm gau}$ of Eq. (3)	0.023	1.2%	1.2%	0.90	$\Delta H = 1.9\sigma$	$\Delta H = 2.4\sigma$
IV	$p_{\rm logn}$ of Eq. (4)	0.023	1.3%	1.1%	0.97	$\Delta H = 1.8\sigma$	$\Delta H = 2.4\sigma$

What about using cosmological simulations ?

$$\delta_k = \frac{1}{N} \sum_{i \neq k} \frac{\hat{\mathbf{r}} \cdot \mathbf{v}_i}{H_G |\mathbf{r}_i - \mathbf{r}_k|},$$

observer

SN host galaxy



CDM, ~10^7 particles !

Turner, Cen & Ostriker (1992)

Advantages of using cosmological simulations

- fully nonlinear evolution
- velocity bias
- realistic positions/velocities of galaxies
- possibility of selecting observers and host galaxies of SNe Ia

$$p(\delta H_0/H_0) \sim p(\delta H_0/H_0 | \text{observer,hosts}) p(\text{observer,hosts})$$

Options:
- observers in MW-like galaxies, voids etc.
- different environments of SN host galaxies
- redshift distribution of SN
- survey geometry: complete/incomplete sky coverage

Jubilee Simulation and Big MultiDark

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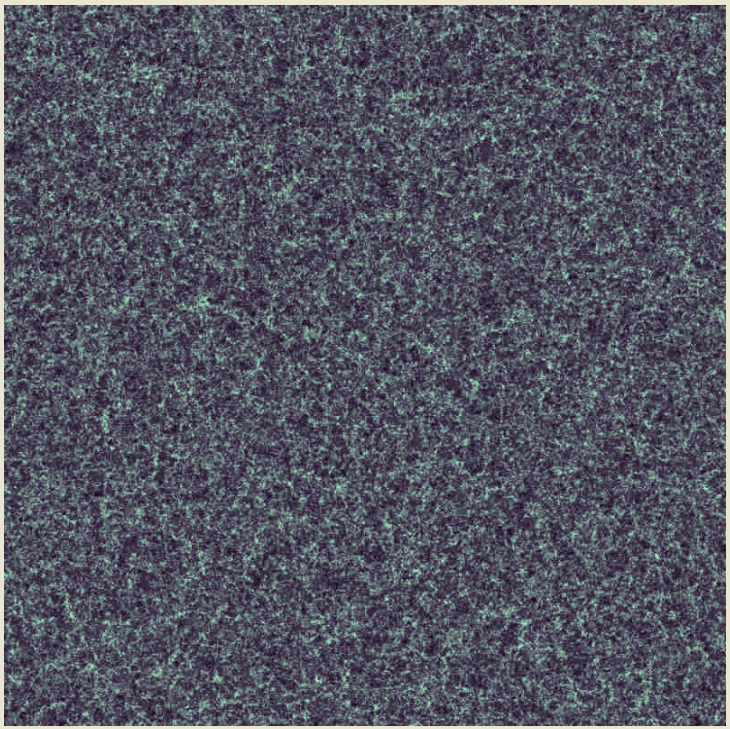
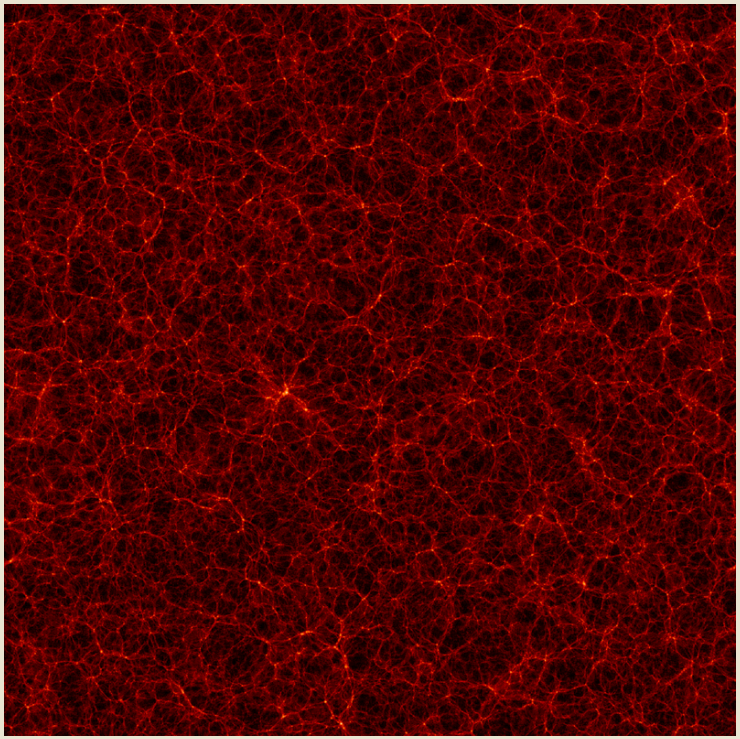
Jubilee
6 Gpc/h
6000^3 particles
min resolved halo mass: $7\times10^{10}M_\odot$
~Planck cosmology



halo distribution
6Gpc/h×6Gpc/h

Big MultiDark
2.5 Gpc/h
3840^3 particles
min resolved halo mass: $2\times10^{10}M_\odot$
~Planck cosmology



DM distribution
1Gpc/h×1Gpc/h

Observers: random positions in space

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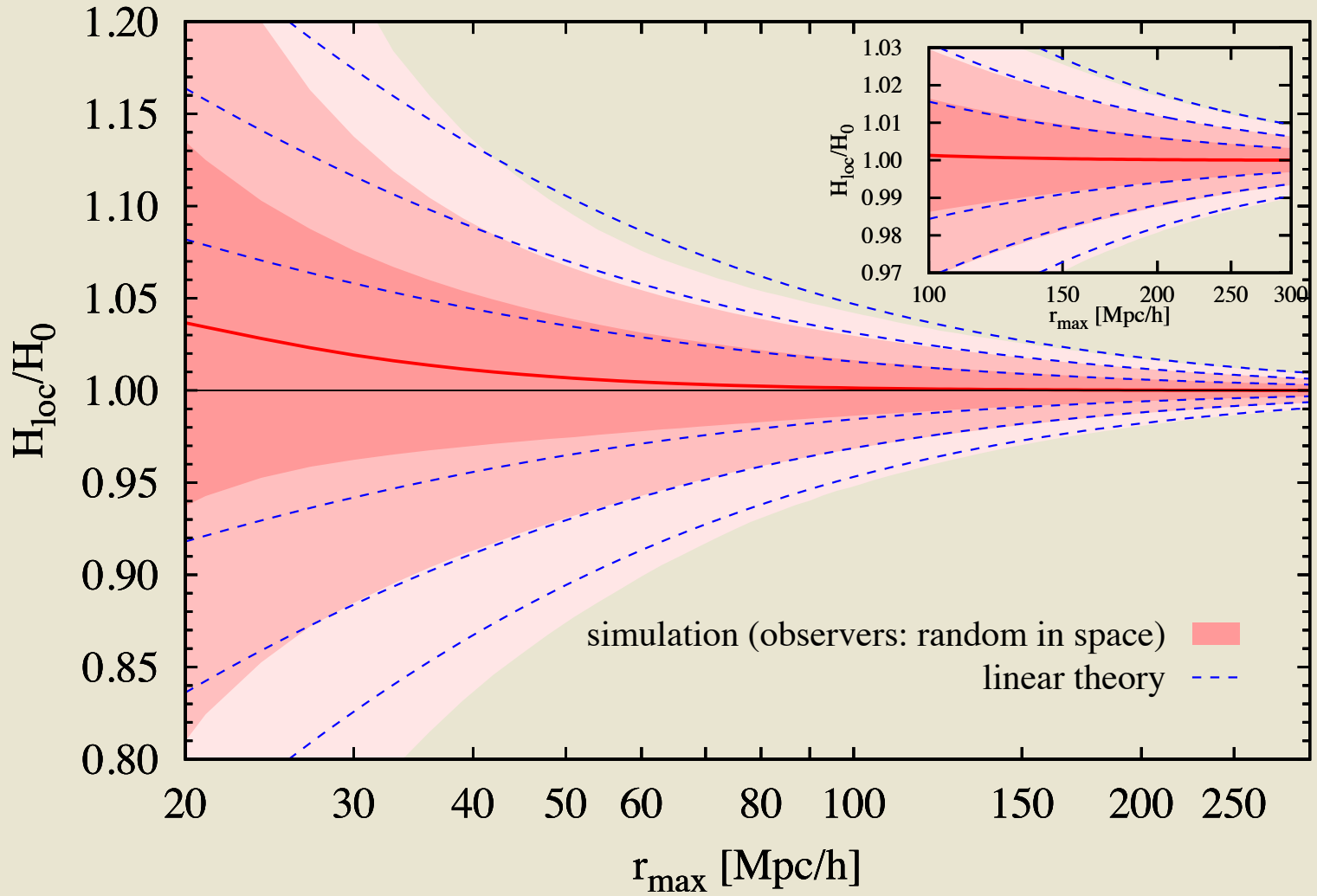
@75 Mpc/h: bias=+0.3%, scatter=2.1%

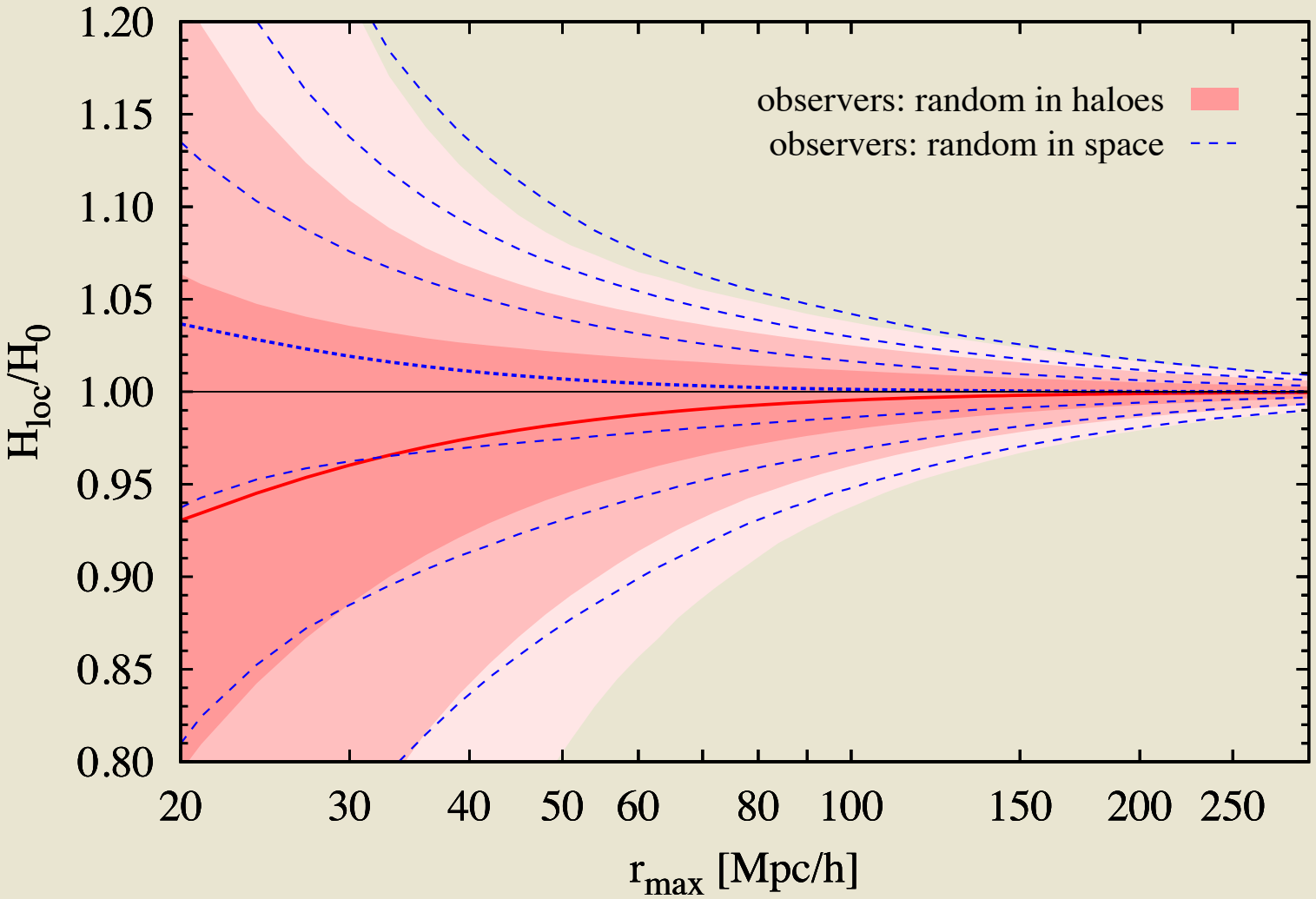


Wojtak et al (2014)

Observers: random DM haloes $M>10^{13}M_{\odot}$

Dark Cosmology Centre

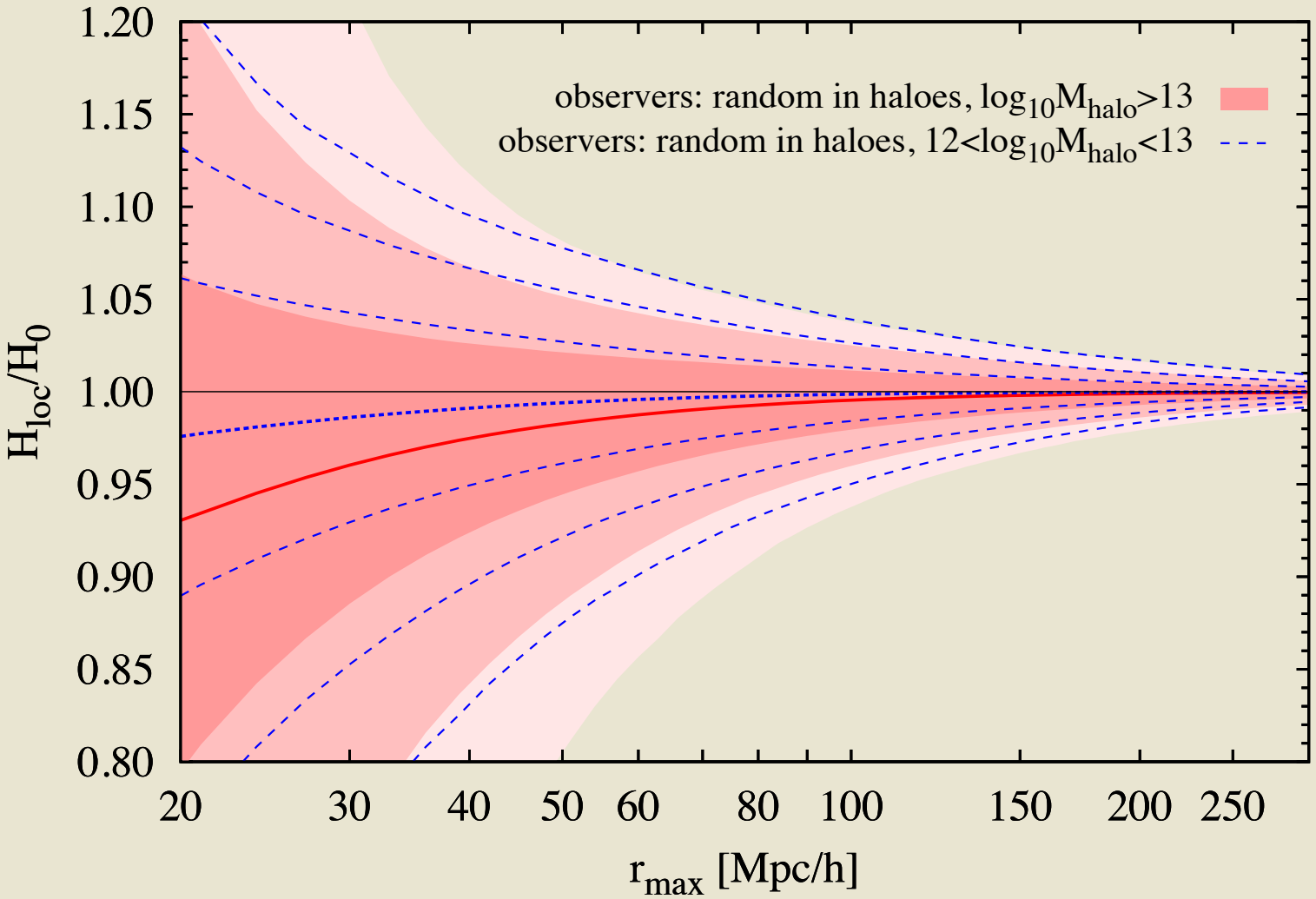
@75 Mpc/h: bias=-0.8%, scatter=2.4%



Observers: random DM haloes $10^{12}M_\odot<M<10^{13}M_\odot$

Dark Cosmology Centre

@75 Mpc/h: bias=-0.3%, scatter=2.1%



Observers: centres of voids

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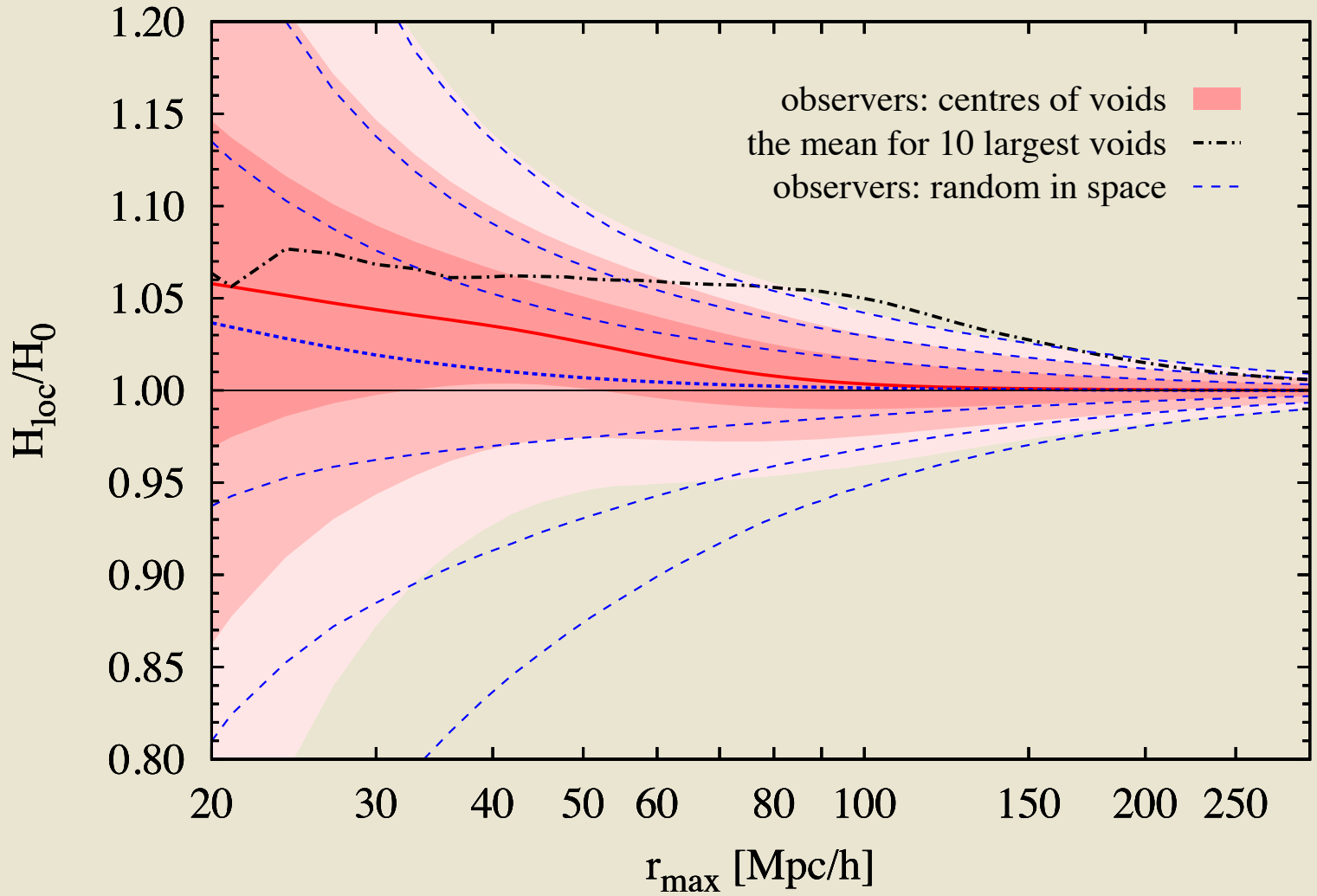
@75 Mpc/h: bias=+1.0%, scatter=1.8%



Predictions for the current sample of SNe Ia

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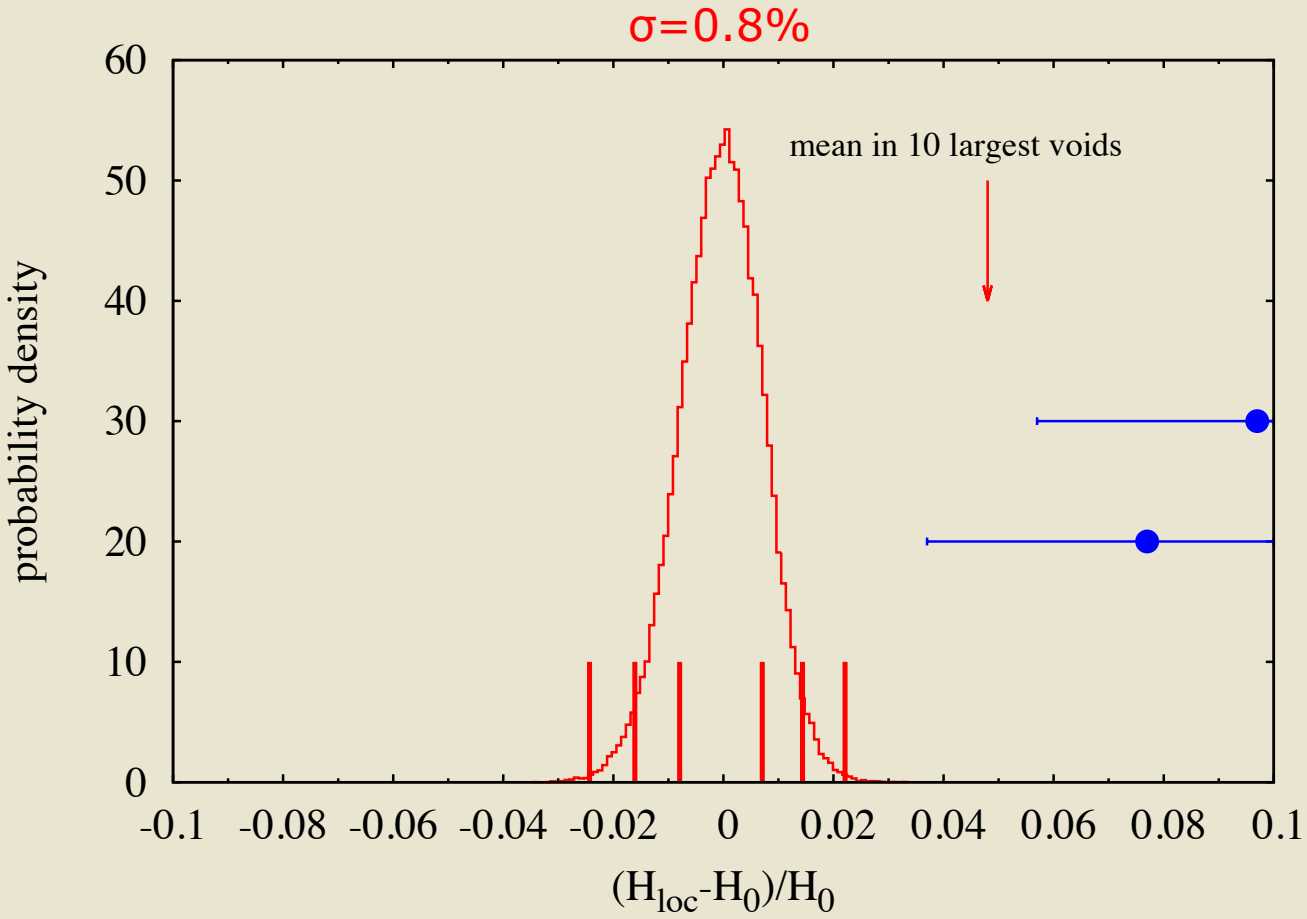
- observers: LG-like haloes $10^{12}M_{\odot}<M<10^{13}M_{\odot}$
- convolution with the redshift distribution of SNe Ia
- $z_{min}=0.023$ (70 Mpc/h) and $z_{max}=0.10$ (300 Mpc/h)



Riess et al (2011)/Planck

Efstathiou (2014)/Planck

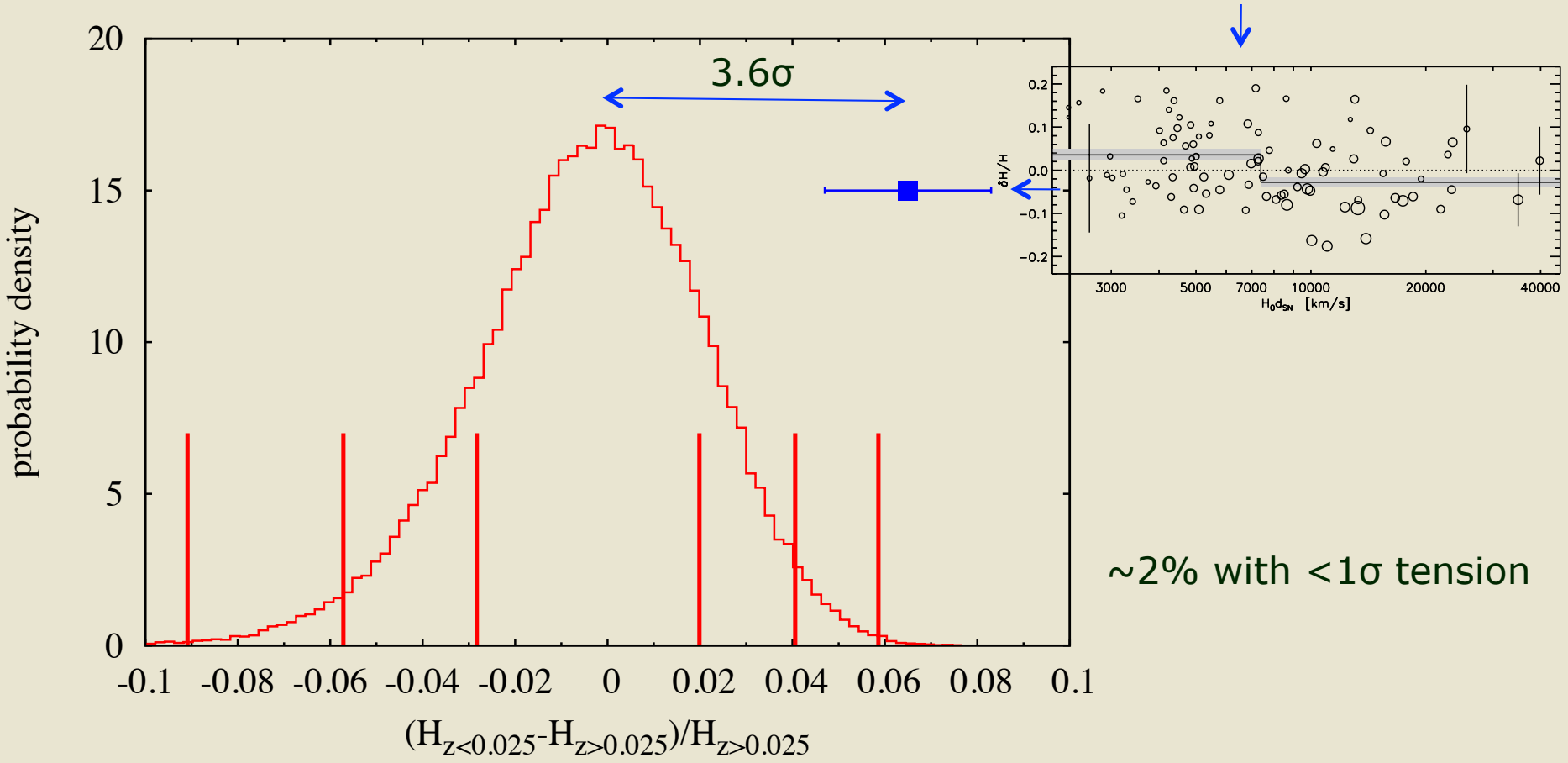
assuming that CMB provides robust measurement of H_0 …

Local Hubble flow at z<0.025 and z>0.025

Dark Cosmology Centre

- observers: LG-like haloes $10^{12}M_{\odot}<M<10^{13}M_{\odot}$
- convolution with the redshift distribution of SNe Ia
- split into: 0<z<0.025 and 0.025<z<0.10

Jha, Riess & Kirschner (2007)



~2% with <1σ tension

Conclusion: 1% error from cosmic variance

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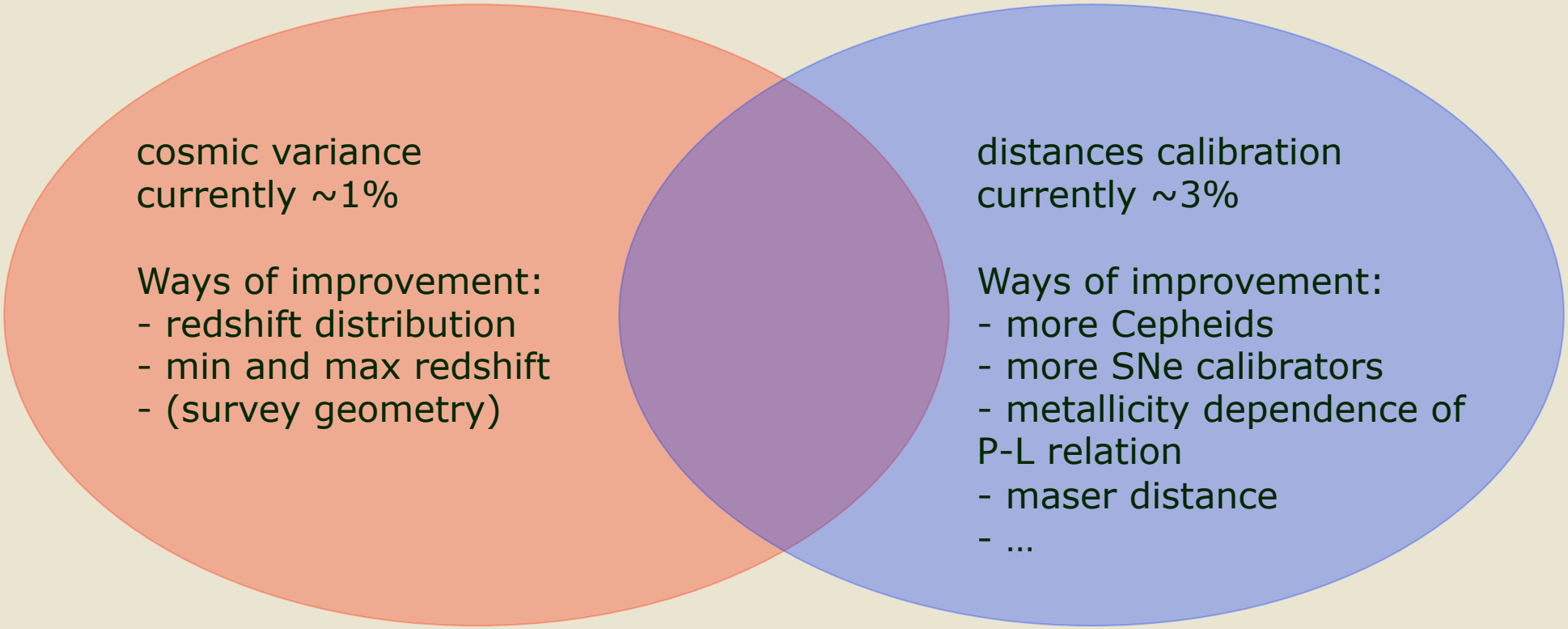


Is there a tension between Planck and the local Universe ?

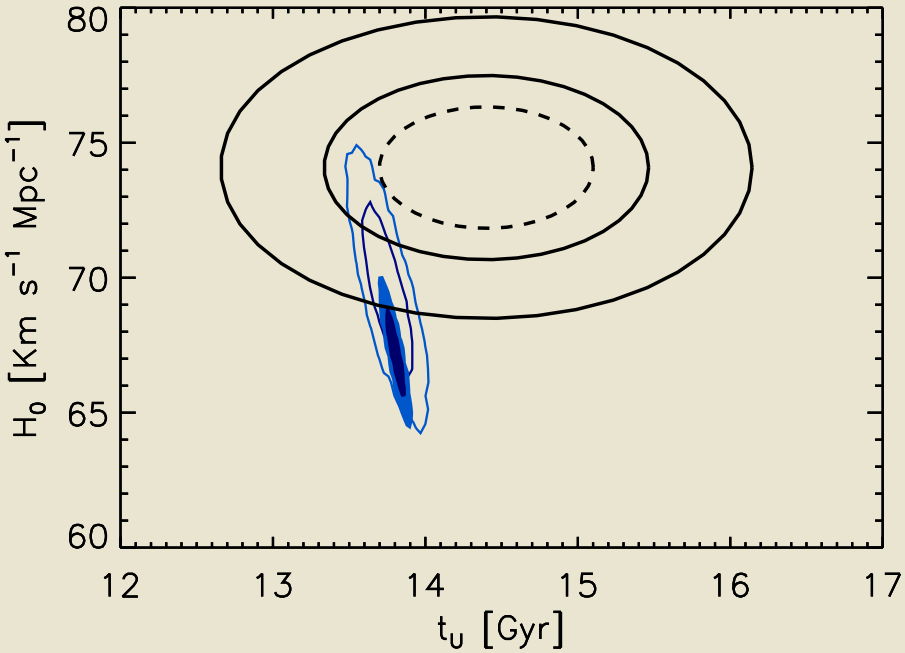
cosmic variance is negligible
in the current error budget

~2σ tension in terms
of the H_0 determination

not significant

evidence for tension when
including local constraints on the
age of the Universe

strong

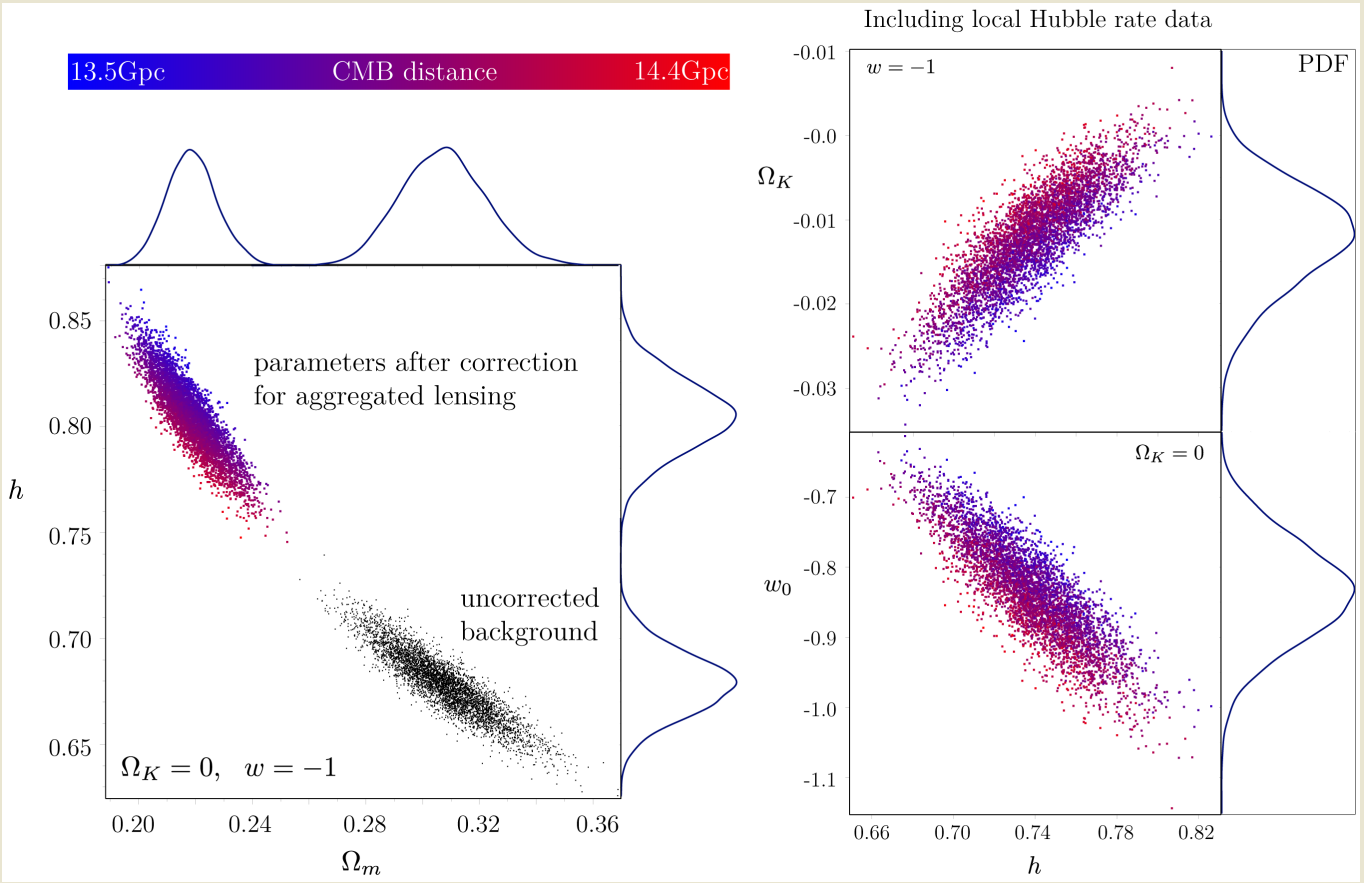


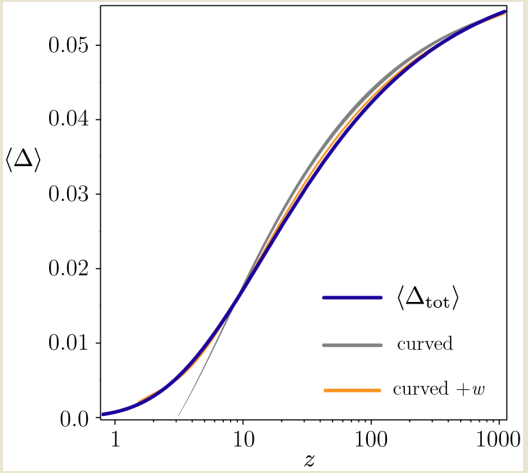
(0-2)σ not significant
(2-3.2)σ substantial
(3.2-4.5)σ strong

Verde, Protopapas & Jimenez (2013)

Effect of inhomogeneities in H_0 determination from CMB ?

$$d_A^{\rm eff}(z_s) = \langle d_A(z_s, \boldsymbol{n}) \rangle = \bar{d}_A(z_s)[1 + \langle \Delta \rangle(z_s)]$$





Clarkson, Umeh, Maartens & Durrer (2014)

Where to measure ?

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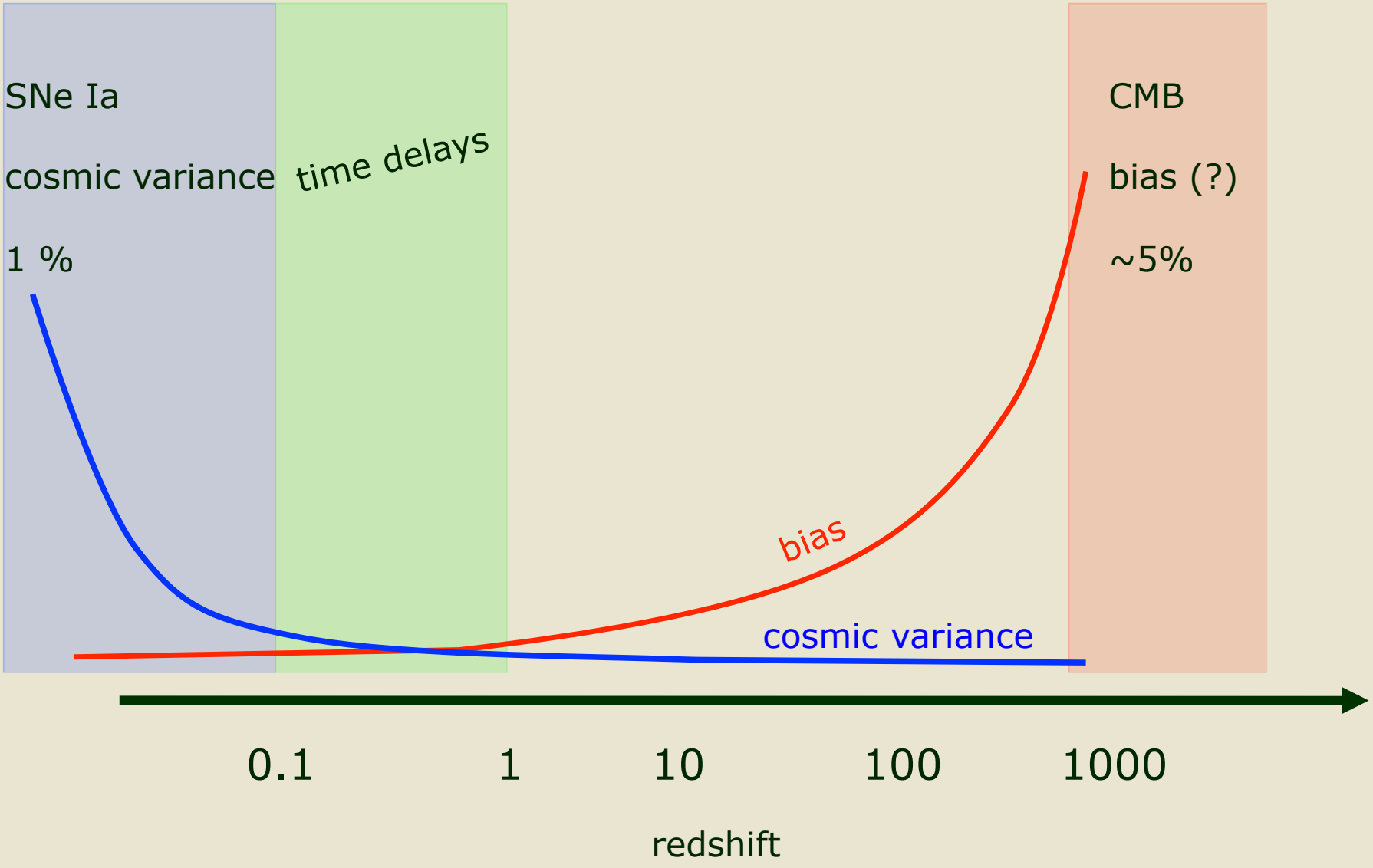

Effect of gravitational redshift on cosmological inference from SNe Ia

Gravitational potential and mass/size scales

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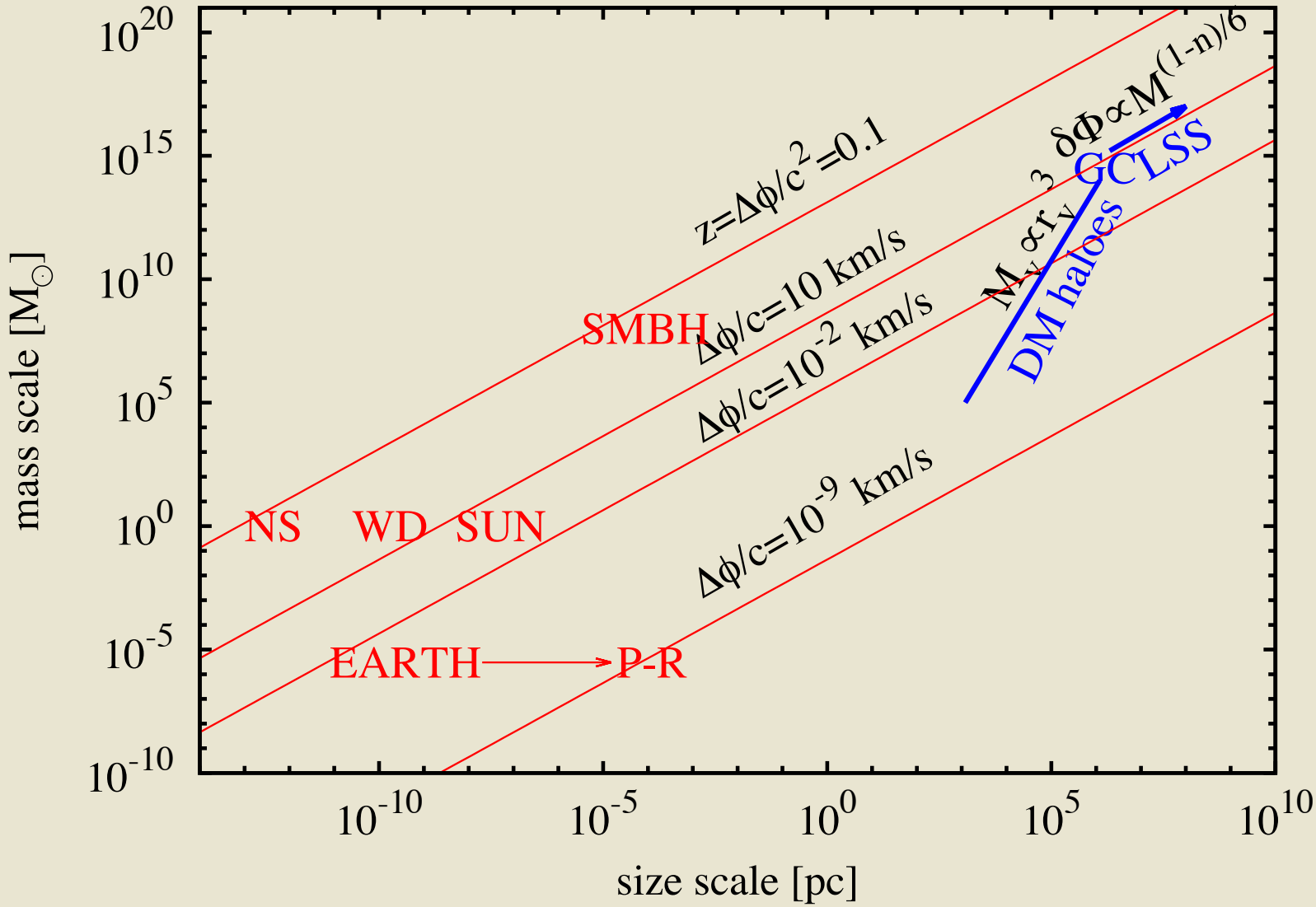

Gravitational redshift: first signal from SDSS clusters

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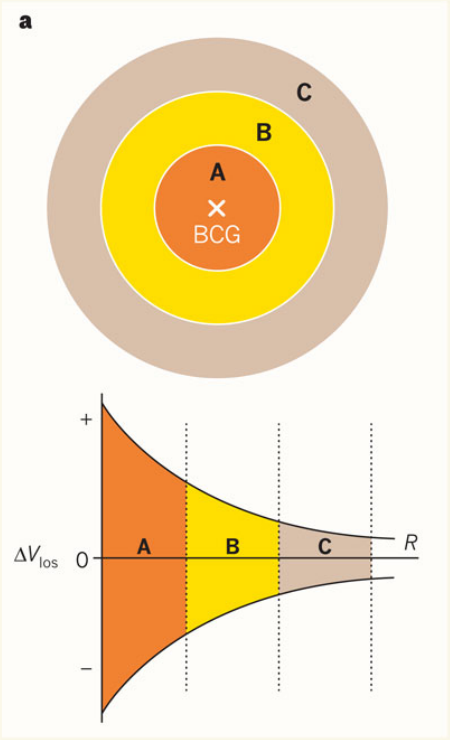
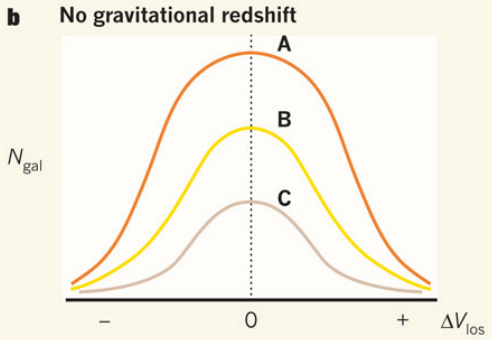
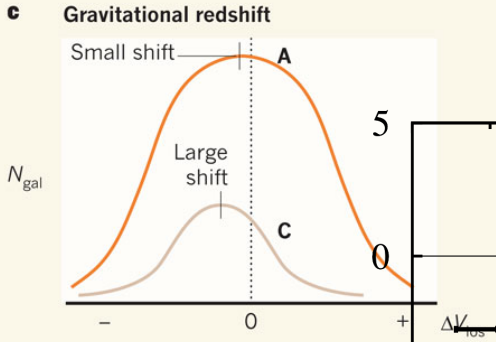
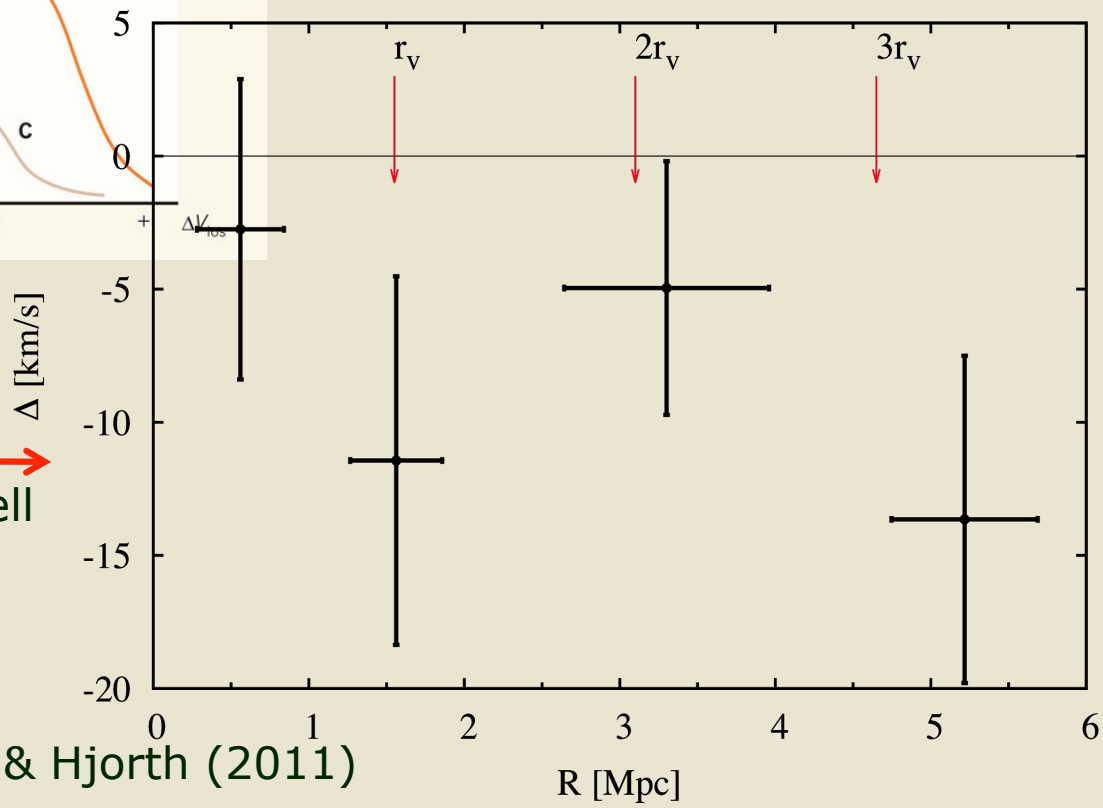






- SDSS
- ~8000 galaxy clusters
- ~10^5 redshifts

Gravitational redshift corresponding to the potential well in galaxy clusters with masses ~$10^{14} M_\odot$ (≈3σ detection)



Wojtak, Hansen & Hjorth (2011)

Gravitational redshift from large-scale structures

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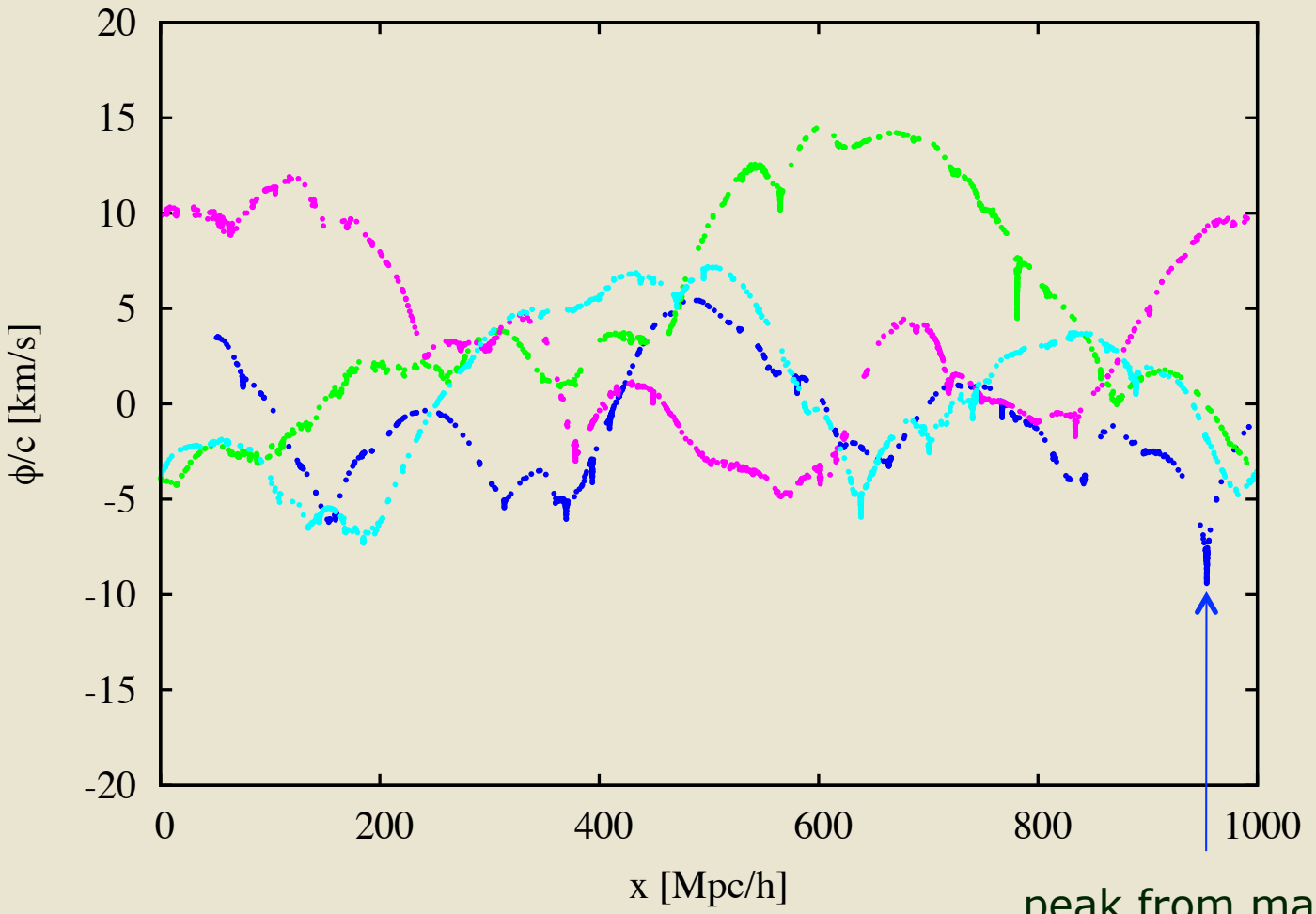
contribution from large-scale structures: +/- 10 km/s



peak from massive DM halo

Wiis, Davis, Wojtak (in prep)

Towards realistic predictions

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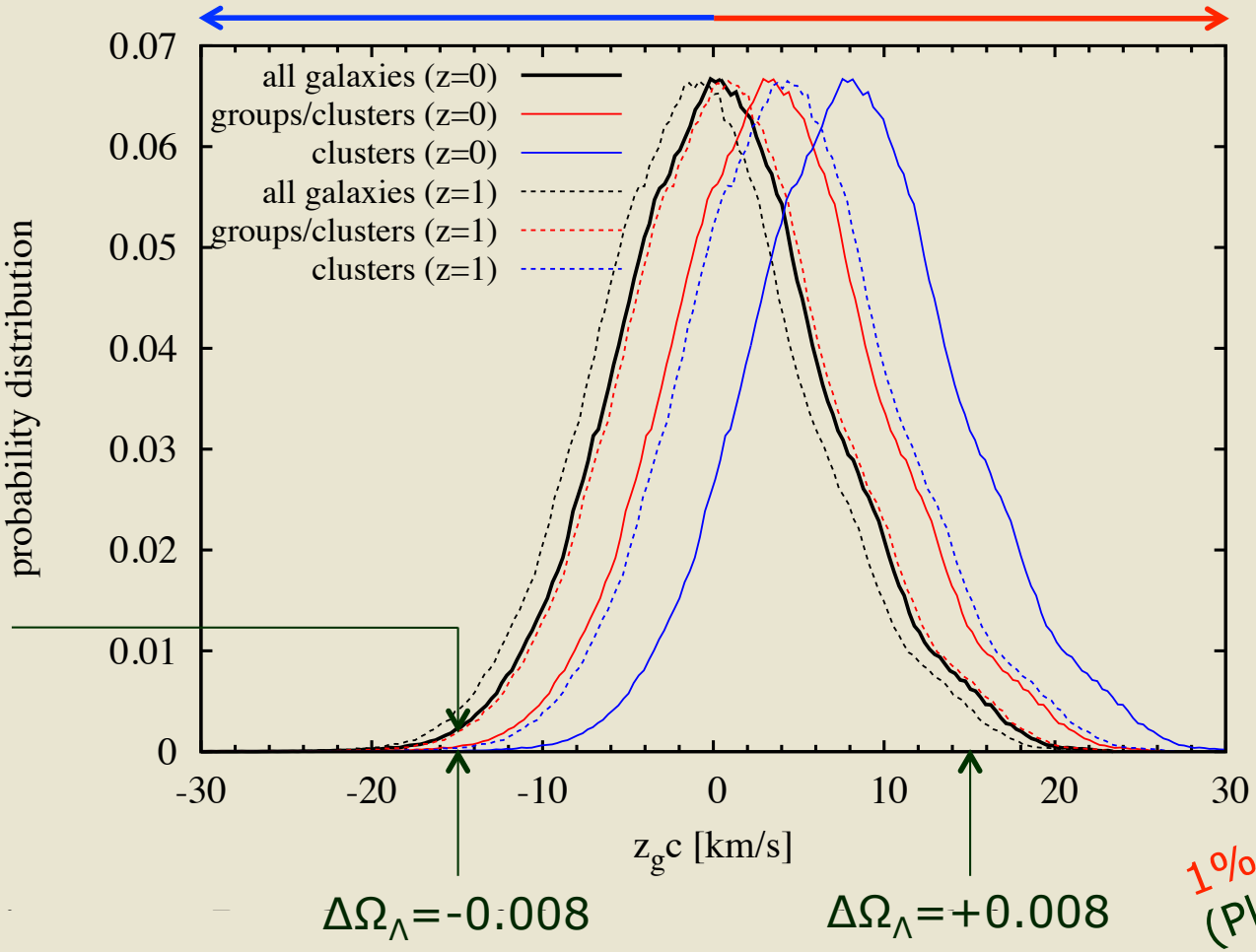
observers in underdense environment
blueshift

observers in overdense environment
redshift



void with
R~70Mpc/h
δρ/ρ~0.4

$\Delta\Omega_\Lambda$=-0.008

$\Delta\Omega_\Lambda$=+0.008

1% precision limit
(Planck: ~3%)

Wiis, Davis, Wojtak (in prep)

Summary

1. H_0 SNe Ia: cosmic variance of ~1%; current measurement accuracy of ~3%
2. H_0 from CMB: 5% bias (?)
3. ~2σ tension between H_0 from SNe Ia and CMB
4. Strong evidence between Planck and local Universe when taking into account constraints on the age of the Universe from local chronometers
5. Gravitational redshift from LSS: ~20 km/s
6. Impact of the gravitational redshift on measurement of cosmological parameters from SNe Ia:

   $\Delta\Omega_\Lambda/\Omega_\Lambda \approx 1\%$