Title: Imprints of primordial non-gaussianity on large-scale structure

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Abstract:

Imprints of Primordial Nongaussianity on Large-scale Structure

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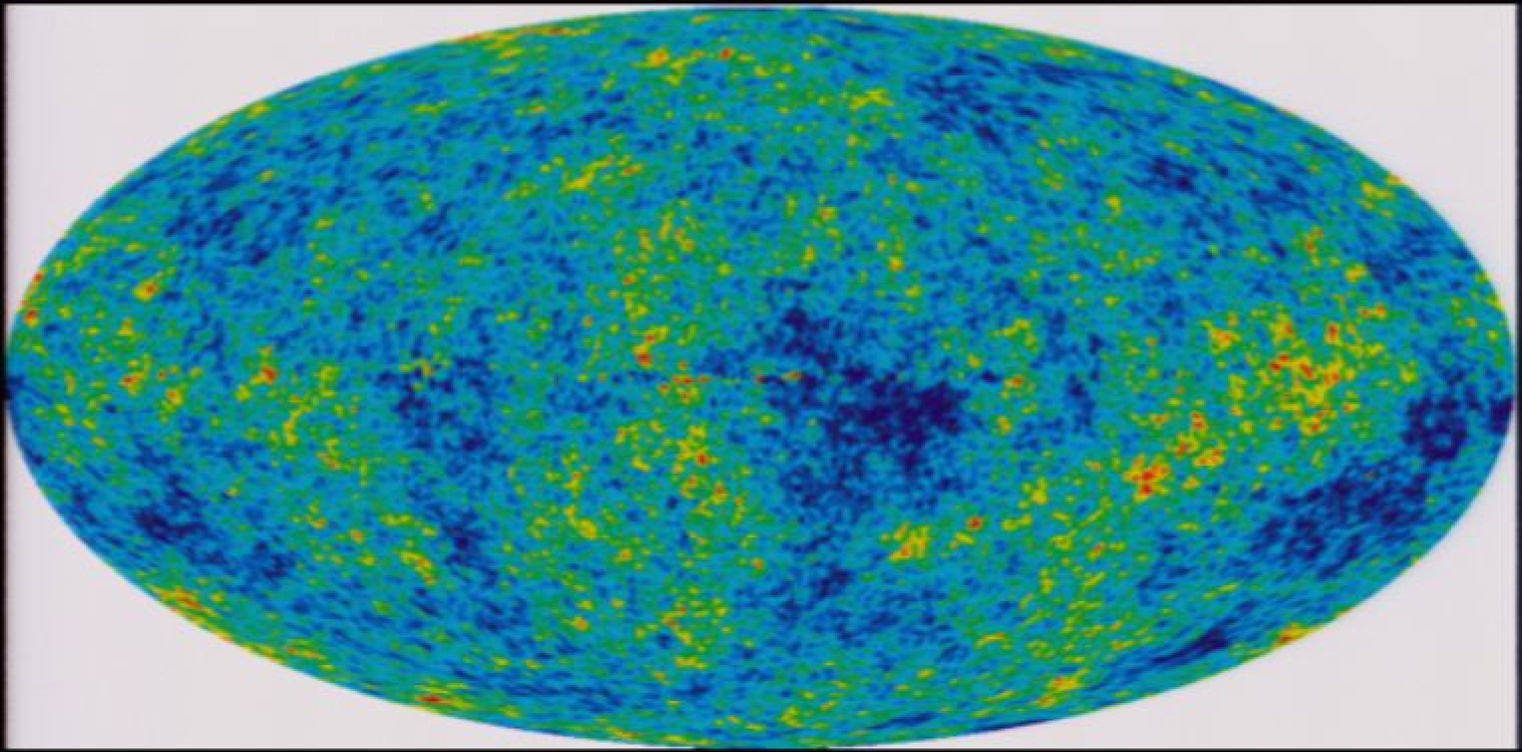
Alex Shirokov (CITA)

Some slides courtesy of O. Doré

arXiv:0710.4560 (PRD, in press)

Initial conditions in our universe



Generic inflationary predictions:

- Nearly scale-invariant spectrum of density perturbations
- Background of gravity waves
- (Very nearly) gaussian initial conditions

Inflation generically predicts (very nearly) gaussian random fluctuations

- Nongaussianity is proportional to slow-roll parameters, V′/V and V″/V
- Reasonable and comminly used approximation $\Phi = \phi + f_{NL}(\phi^2 - \langle\phi^2\rangle)$
- If Φ is Gaussian, then $f_{NL}=O(0.1)$, which is

basically too small to ever measure

- More exotic inflationary models can produce observable NG, however

Salopek & Bond 1990; Maldacena 2003;
Seery & Lidsey 2005;
Chen, Easther & Lim 2008

Brief history of NG measurements: 1990's

Early 1990s; COBE: Gaussian CMB sky (Kogut et al 1996)

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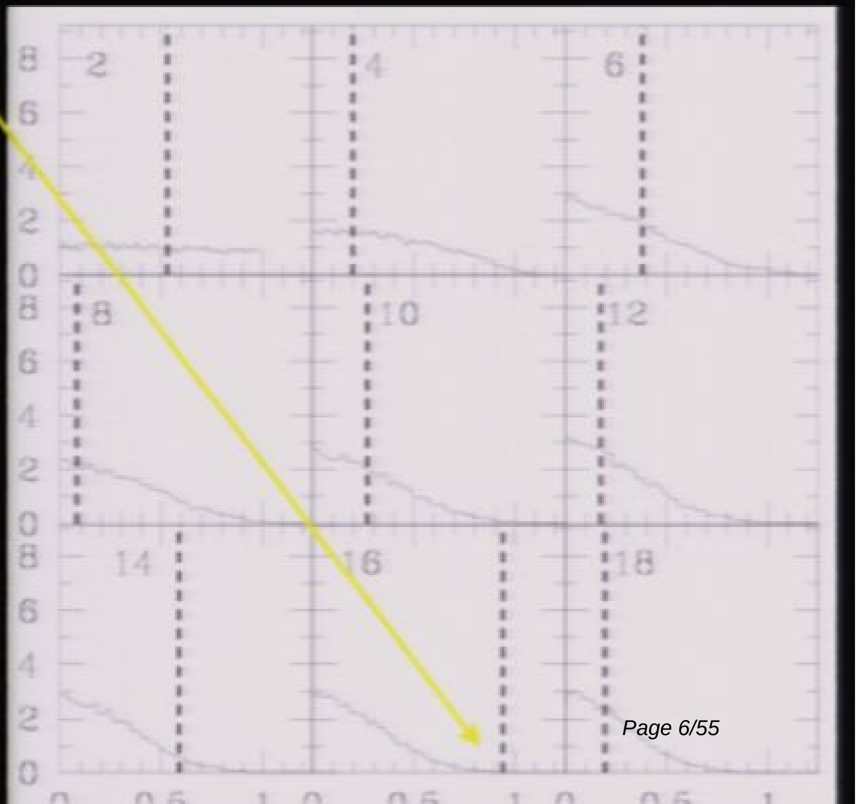

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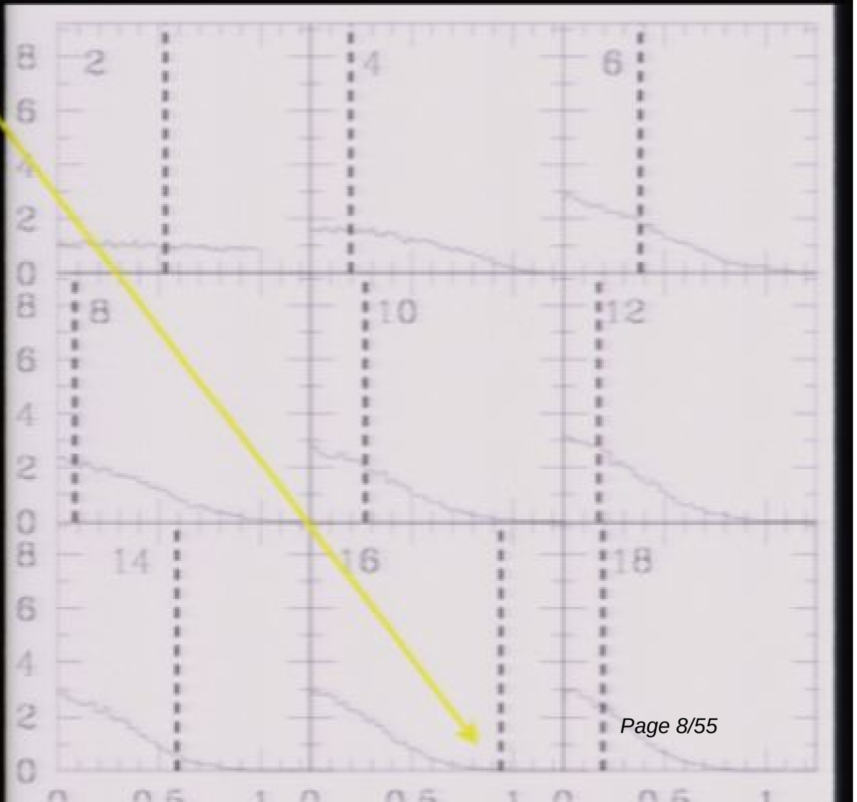
and anyway isn't unexpected given all
ispectrum configurations you can measure;
omatsu 2002)



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Pre-WMAP CMB: all is gaussian (e.g. MAXIMA; Wu et al 2001)

WMAP pre-2008: all is gaussian

(Komatsu et al. 2003; Creminelli, Senatore, Zaldarriaga & Tegmark 2007)

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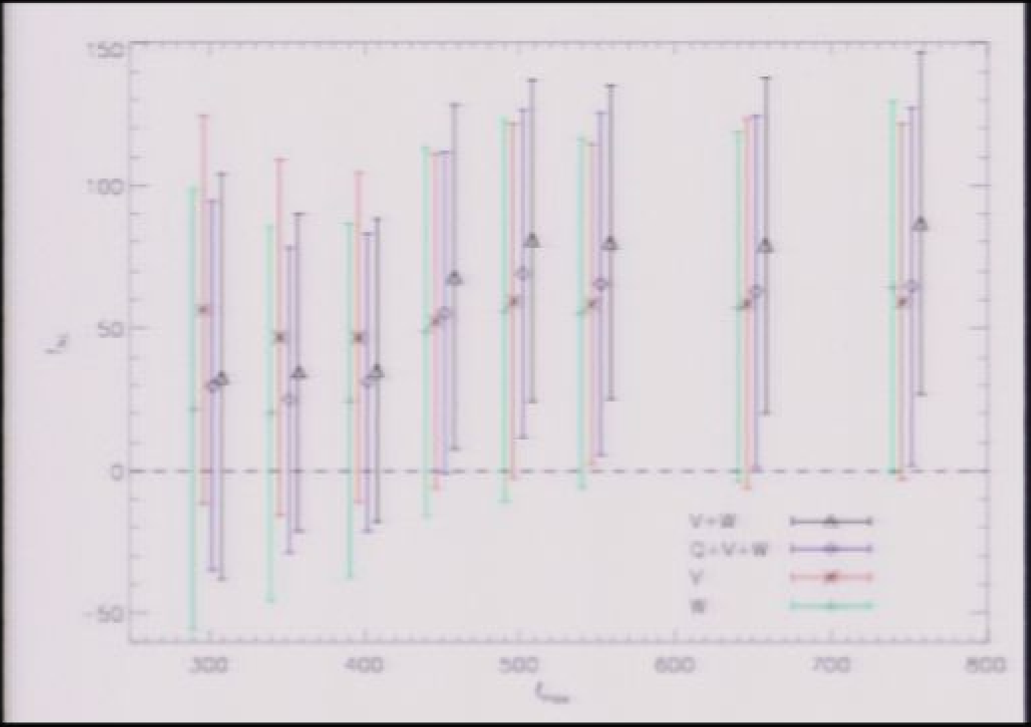
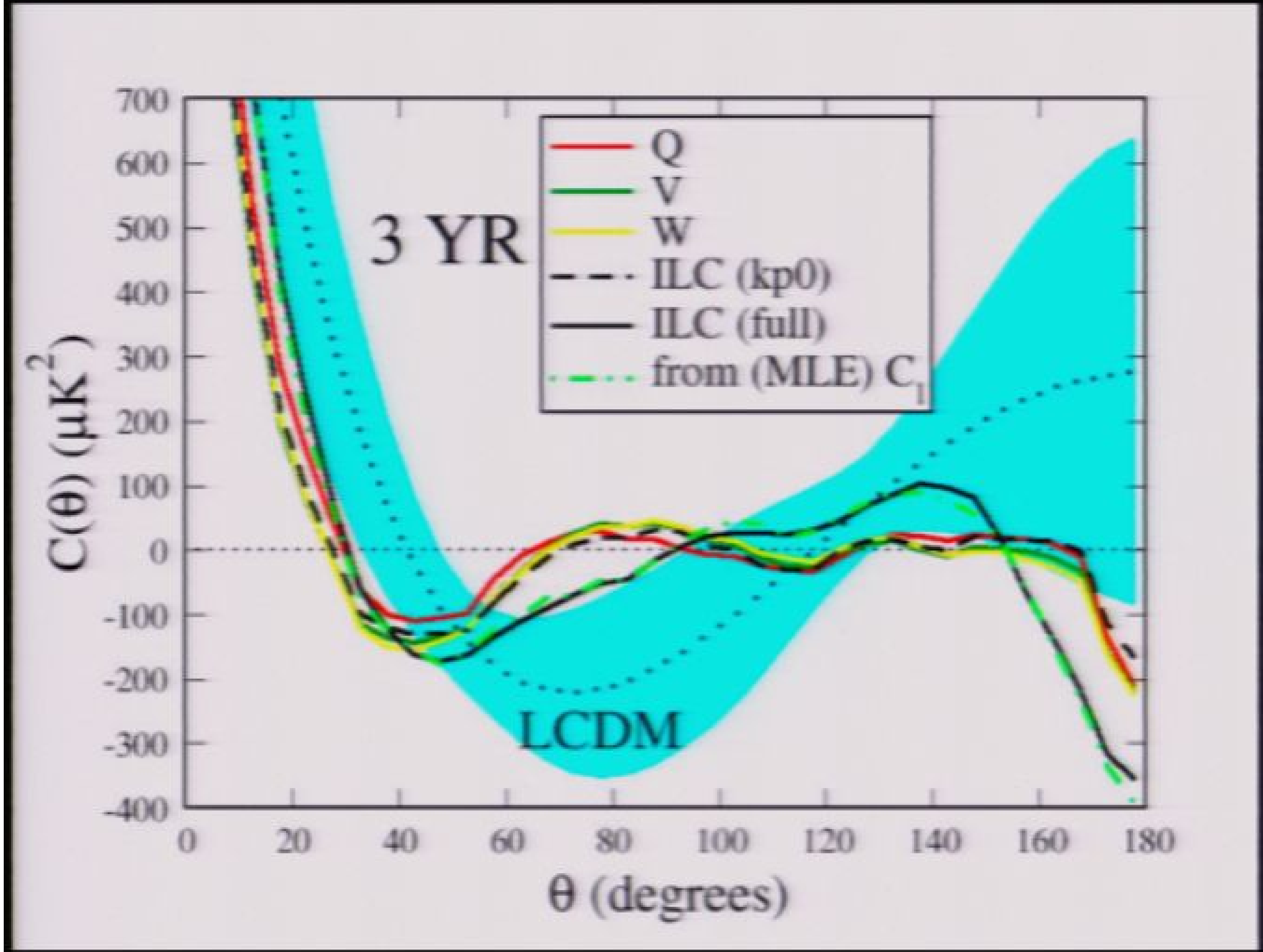
Dec 2007, claim of NG in WMAP
(Yadav & Wandelt arXiv:0712.1148)

$27 < f_{NL} < 147$ (95% CL)



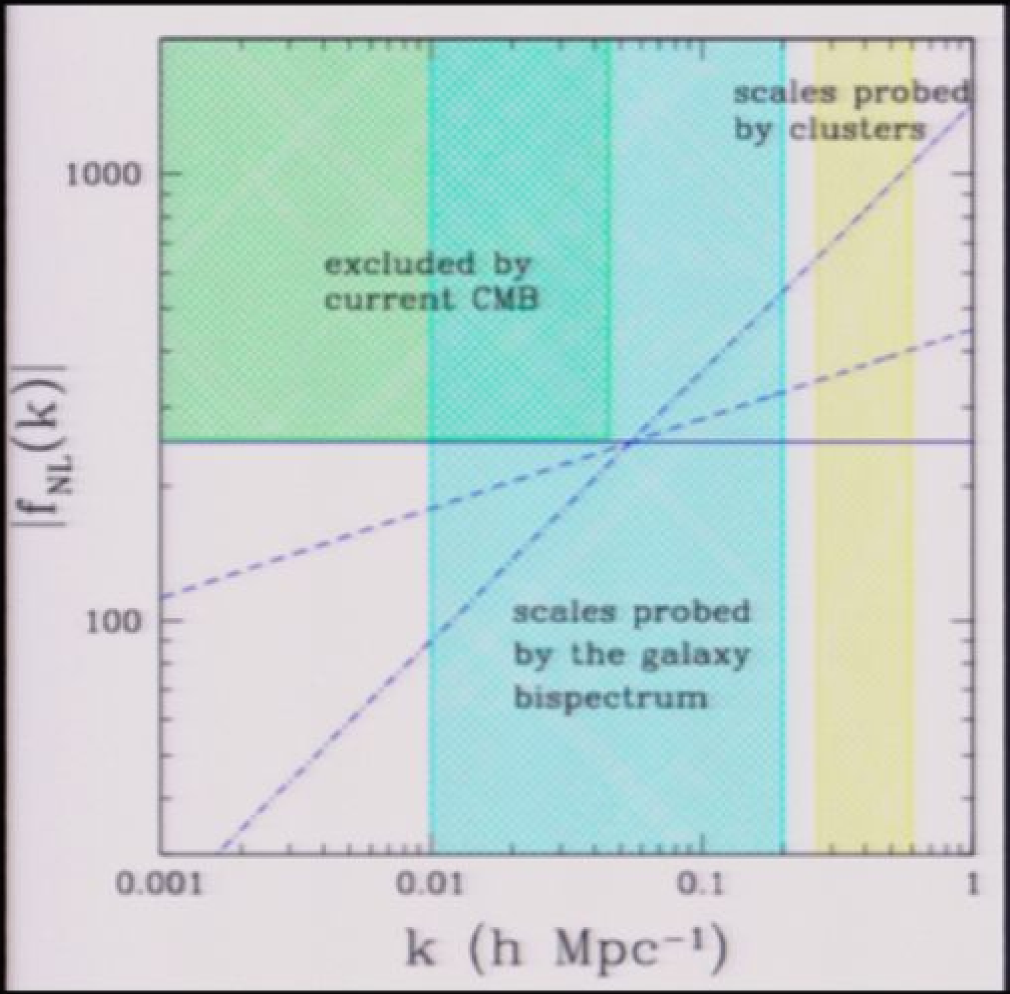
… and also “large-scale anomalies”



e.g. lack of power at >60 deg; significant at 99.96%

Hinshaw et al. 1996 (COBE)
Spergel et al. 2003 (WMAP 1)
Copi, Huterer, Schwarz & Starkman 2007 (WMAP 3)

Constraints from future LSS surveys



Sefusatti, Vale, Kadota & Frieman, 2006

LoVerde, Miller, Shandera & Verde, arXiv:0711.4126

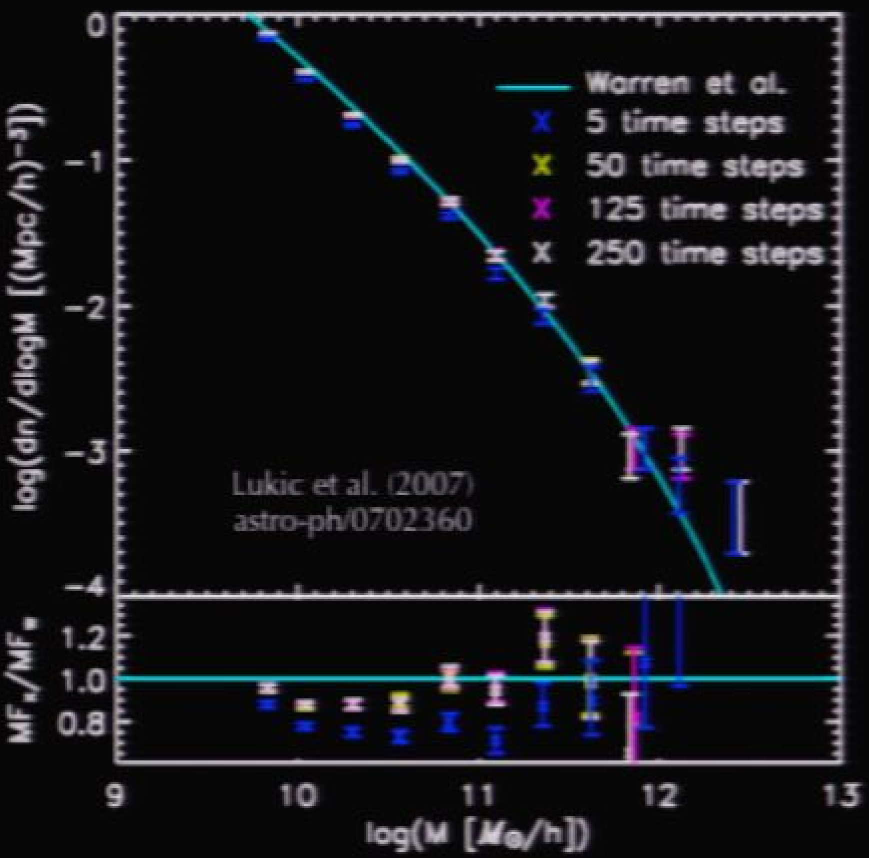
Abundance of halos: the mass function

Lots of interest in using halo counts as a cosmological probe.

- Mass function can be computed precisely (~5%) and robustly for standard cosmology (Jenkins et al. 01, Warren et al. 03)

- dN/dM appears universal — i.e. f(σ) — for standard cosmologies

$$\sigma^2(M,z) = \frac{1}{2\pi^2}\int_0^\infty k^2 P(k) W^2(k,M)\,dk$$



Lukic et al. (2007)
astro-ph/0702360

Mass function, usual analytic approach

Press & Schechter 1974:

$$\frac{dn}{dM}dM = \frac{\rho_M}{M}\left|\frac{dF}{dM}\right| dM \qquad F(>M) = 2\int_{\delta_c/\sigma(M)}^{\infty} P_G(\nu)d\nu$$

therefore $$\left(\frac{dn}{d\ln M}\right)_{\rm PS} = 2\,\frac{\rho_M}{M}\frac{\delta_c}{\sigma}\left|\frac{d\ln\sigma}{d\ln M}\right| P_{\rm G}(\delta/\sigma)$$

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follow EPS, then expand P_{NG} in terms of skewness, do the integral

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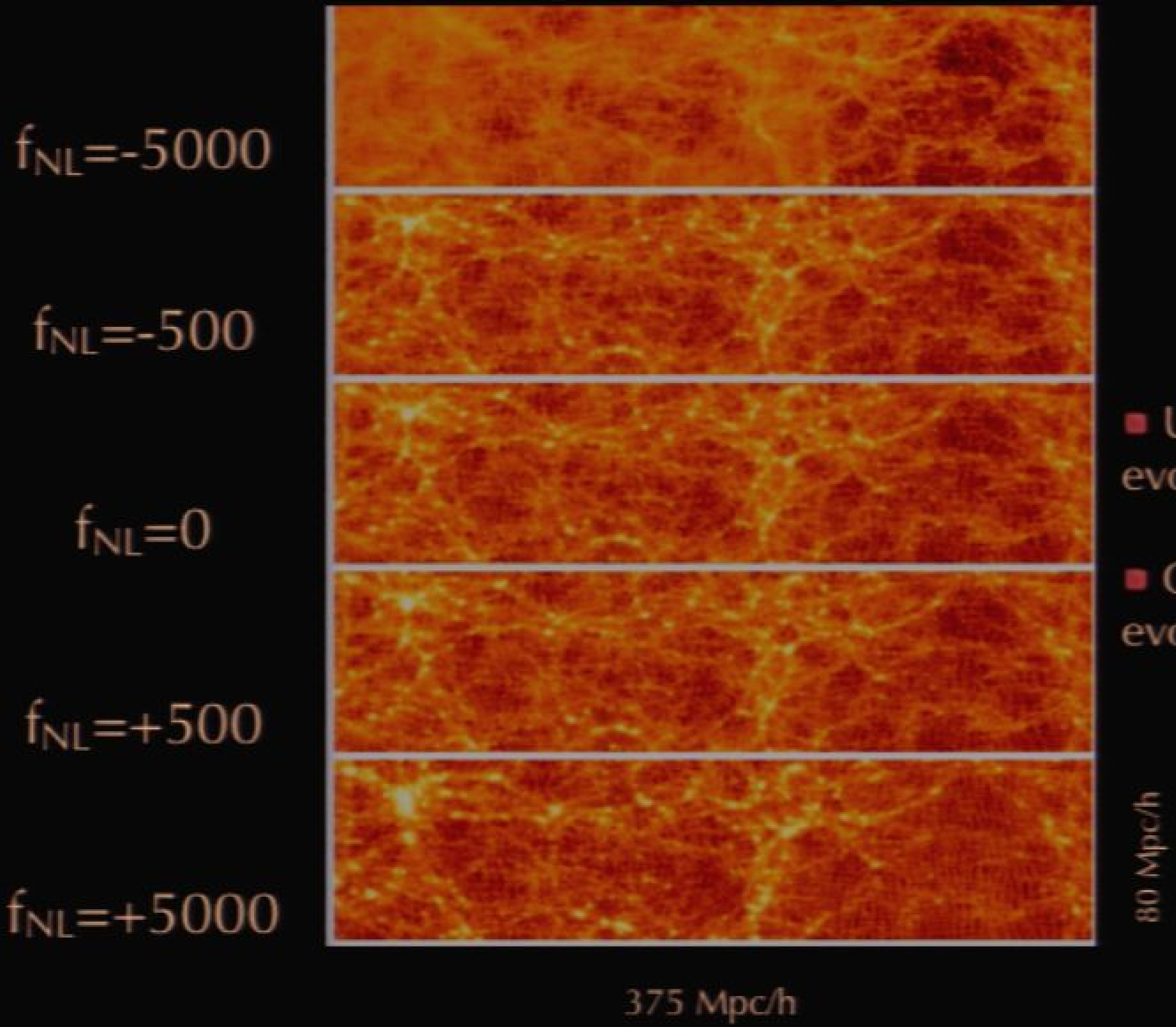
Need to check these formulae with simulations

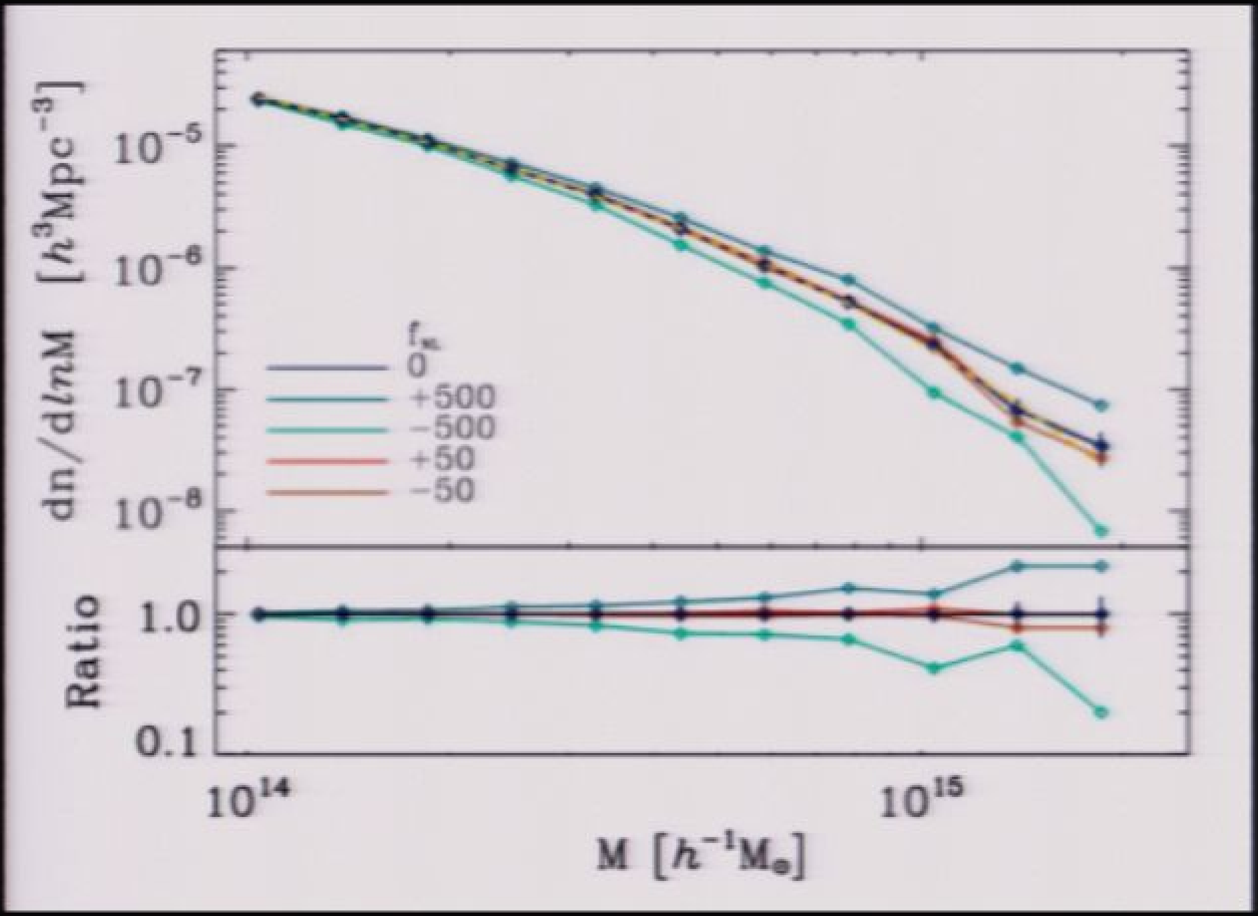
Simulations with nongaussianity (f_{NL})



- Under-dense region evolution decrease with f_{NL}
- Over-dense region evolution increase with f_{NL}

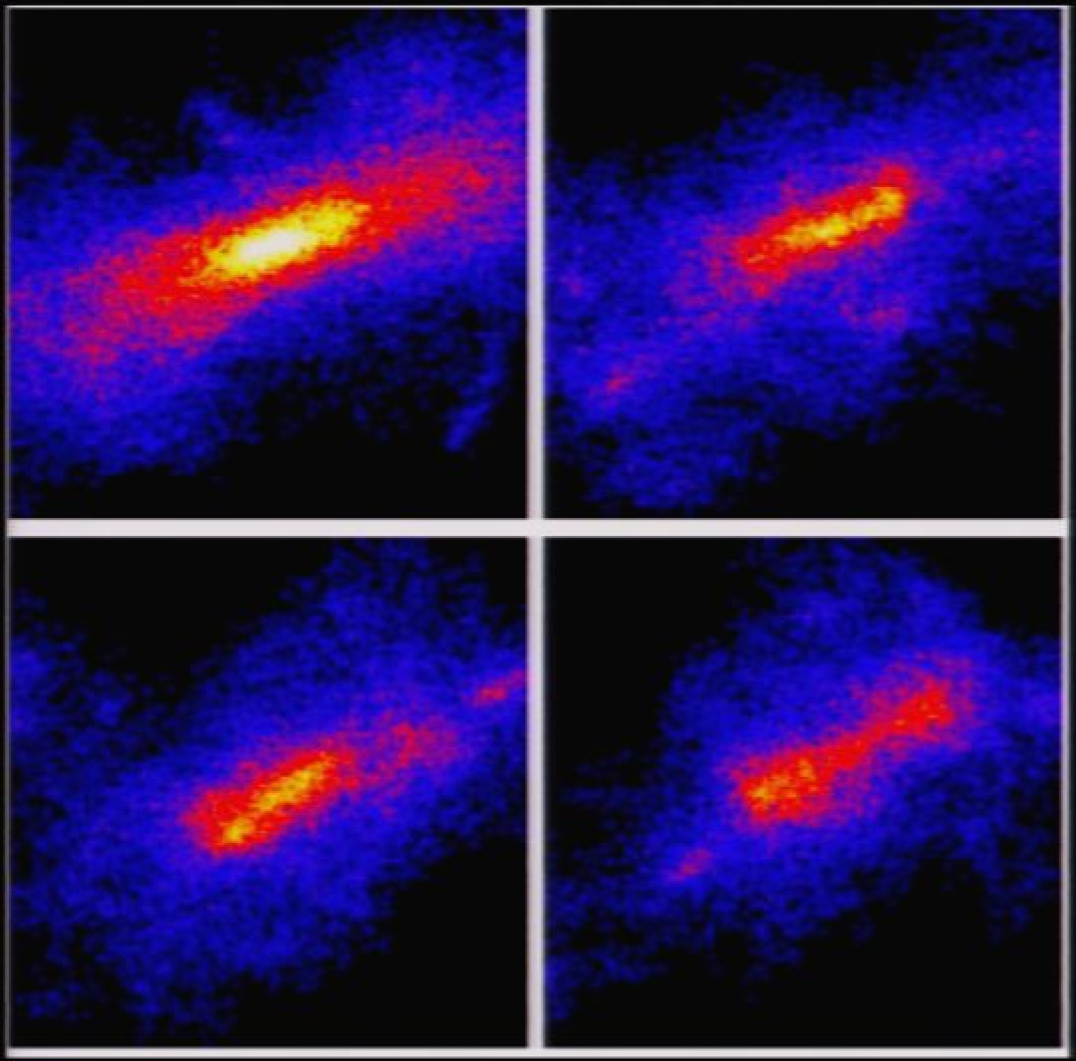
- Same initial conditions, different f_{NL}
- Slice through a box in a simulation $N_{part}=512^3$, L=800 Mpc/h

The measured halo mass function



- 512^3 (1024^3) particle simulations with box size 800 (1600) Mpc/h
- Gracos code (www.gracos.com); add quadratic Phi term in real space; apply transfer function in Fourier space

Looking at one individual cluster



f_{NL}=+5000
M=1.2 10^{16} $M_\odot$

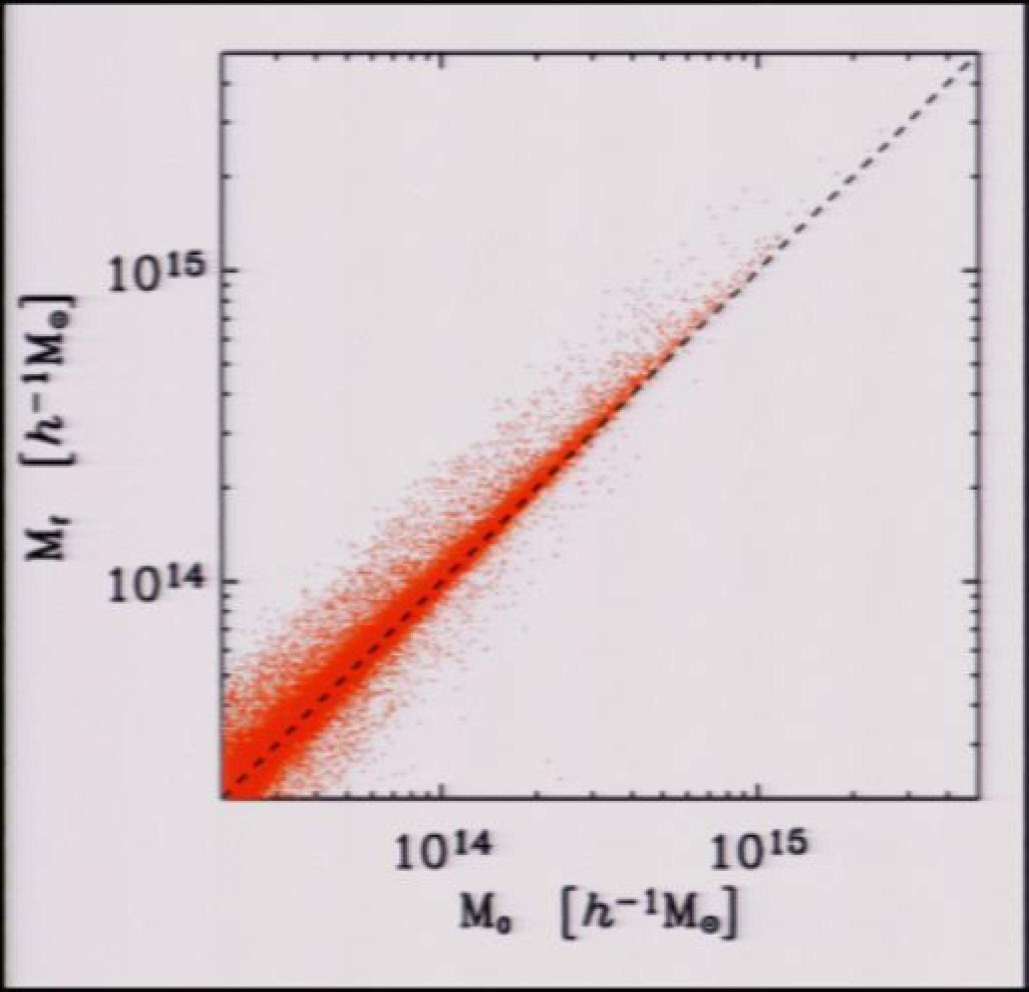
f_{NL}=+500
M=5.9 10^{15} $M_\odot$

f_{NL}=0
M=5.1 10^{15} $M_\odot$

f_{NL}=-500
M=4.3 10^{15} $M_\odot$

- Most massive cluster in our simulation
- For small enough f_{NL}, same peaks arise, with different heights (implying different masses)
- Can we extend to any cluster?

Building the $P(M_f|M_0)$ distribution



$f_{NL} = 500$

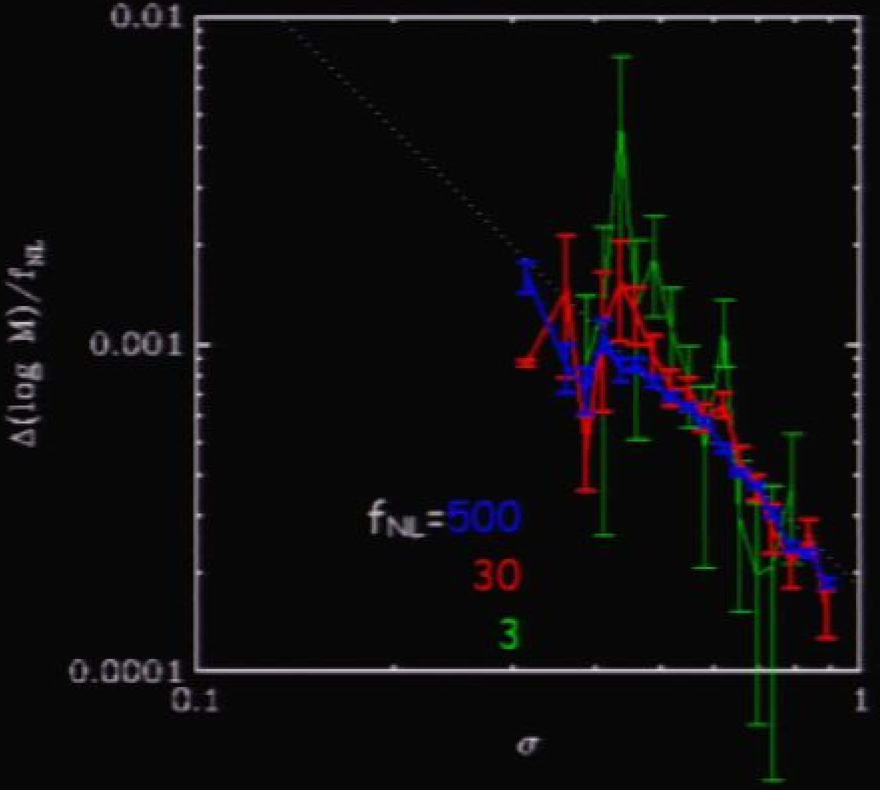
- Idea: identify the *same* cluster for different f_{NL}, keep track how its mass changed!
- Significantly saves computational expenses

Towards a fitting function

- If the mapping $M_0 \rightarrow M_f$ is described by a PDF $dP/dM_f(M_0)$, then the non-gaussian mass function is a convolution over the (known) gaussian mass function

$$\boxed{\frac{dN}{dM} = \int \frac{dP(M_f|M_0)}{dM_f} \frac{dN}{dM_0} dM_0}$$

(e.g. Jenkins)

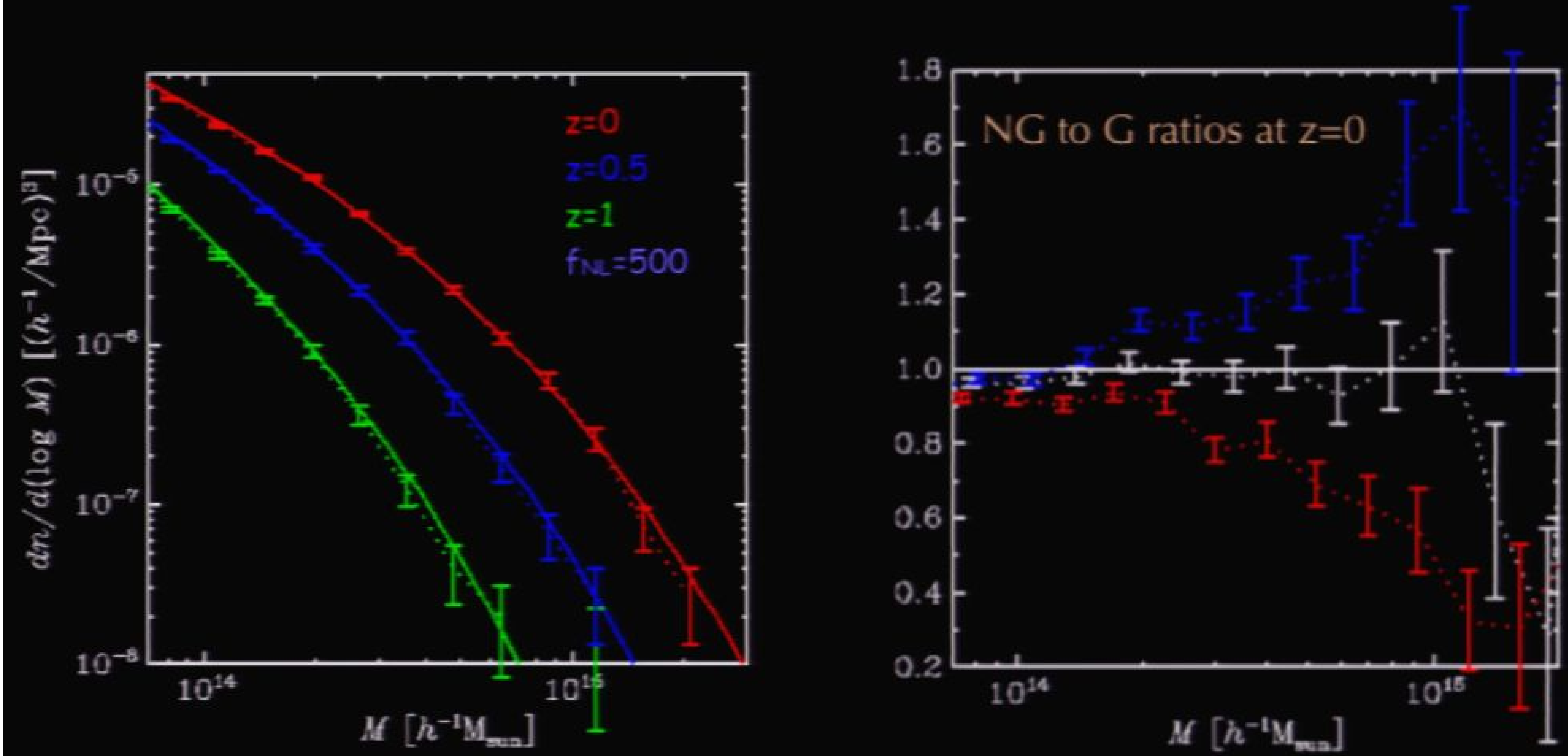


- We thus aim at fitting the mean and rms of Δ(log M)(z)
- The simplest thing to do is to consider a… Gaussian…
- We'd expect the mean of the PDF to be shifted by Δ(log M)∝f_NL
- We find that a good fit is given by

$$\left[\frac{\bar{M}_f}{M_0}\right] - 1 = 6.\ 10^{-5} f_{NL} \sigma_8\ \sigma(M_0,z)^{-2}$$

$$\sigma\left(\left[\frac{\bar{M}_f}{M_0}\right] - 1\right) = 0.012\ (f_{NL}\sigma_8)^{0.4}\ \sigma(M_0,z)^{-0.5}$$

Mass function from N-body simulation and our fitting formula



Dalal,, Doré, Huterer & Shirokov, arXiv:0710.4560

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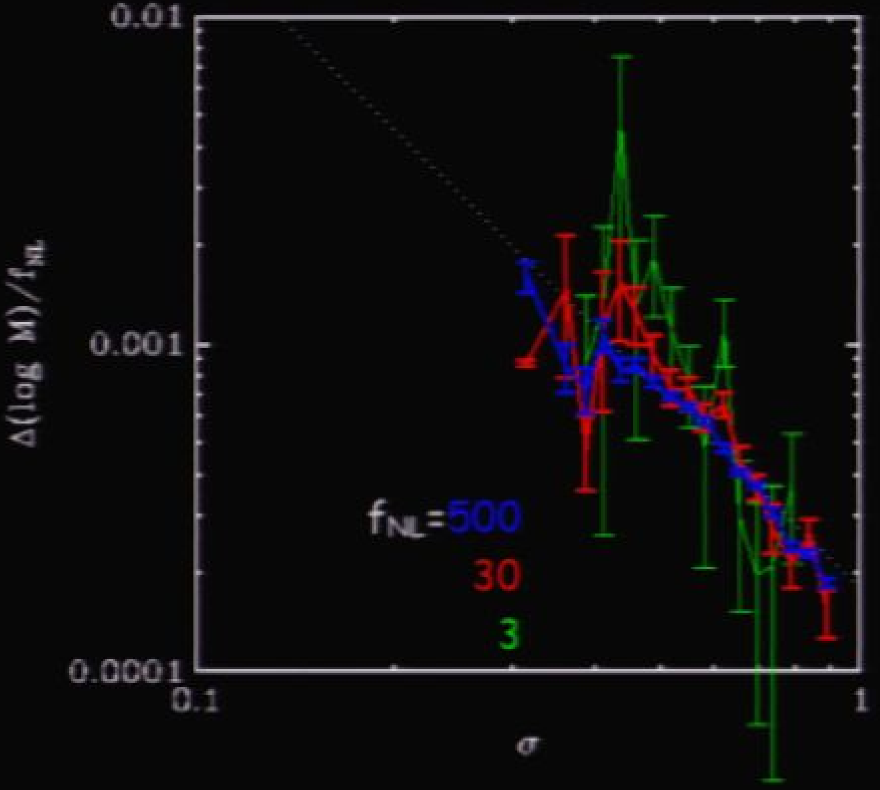

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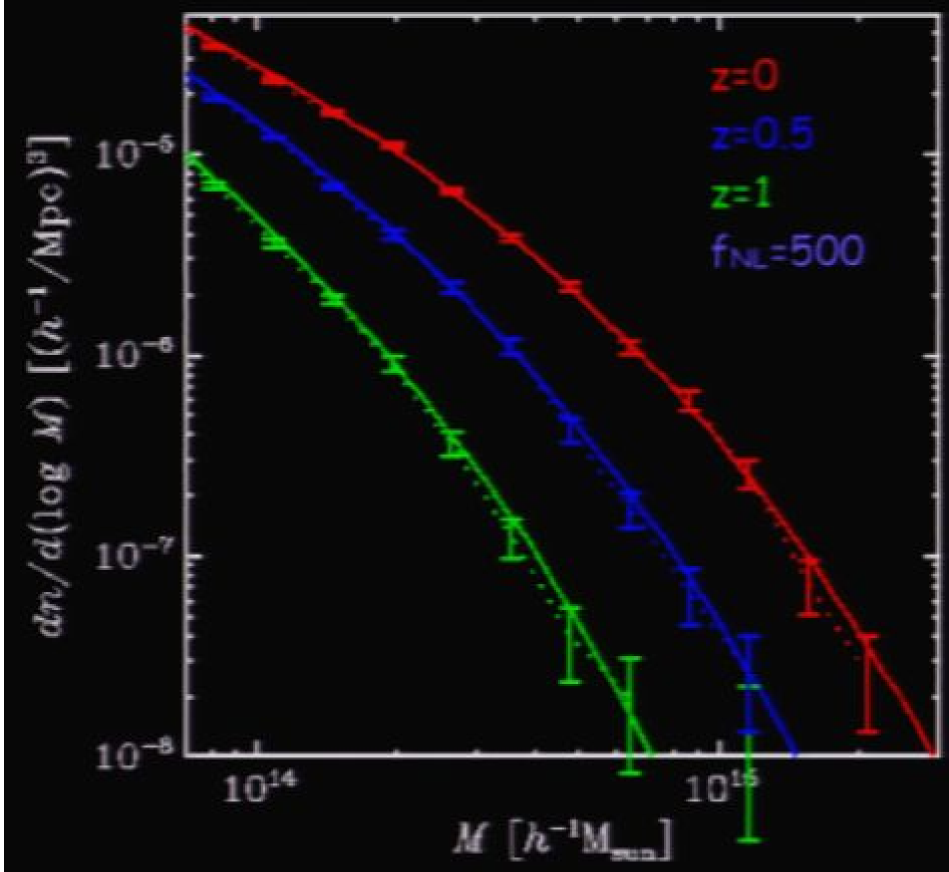

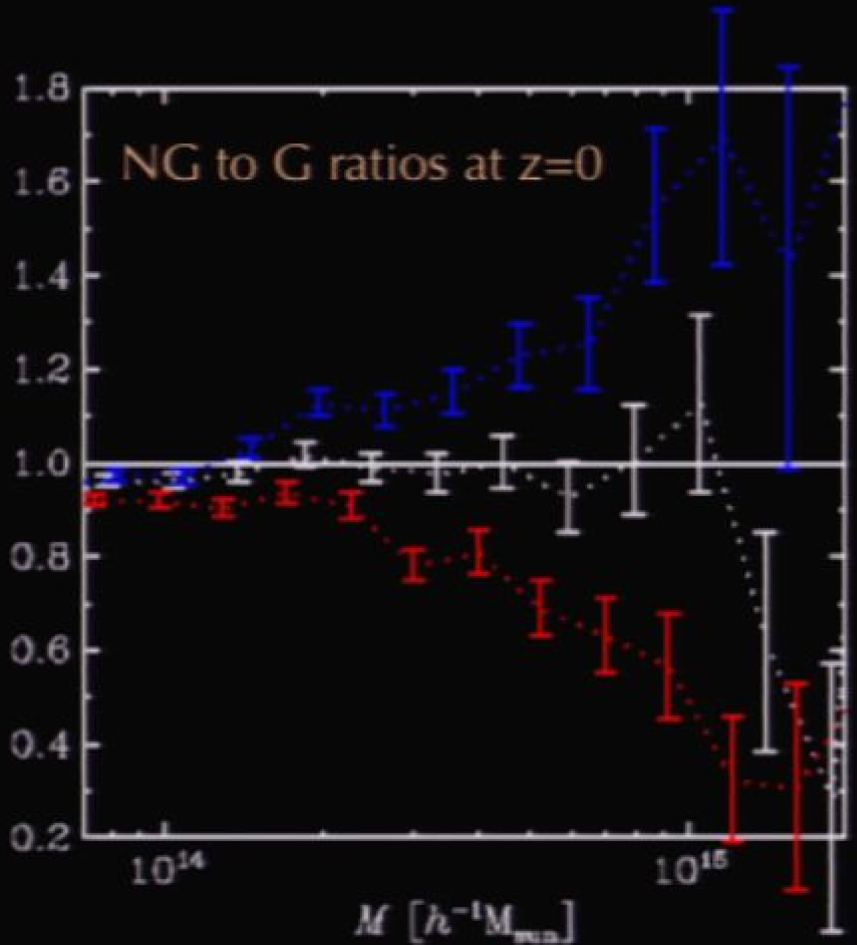

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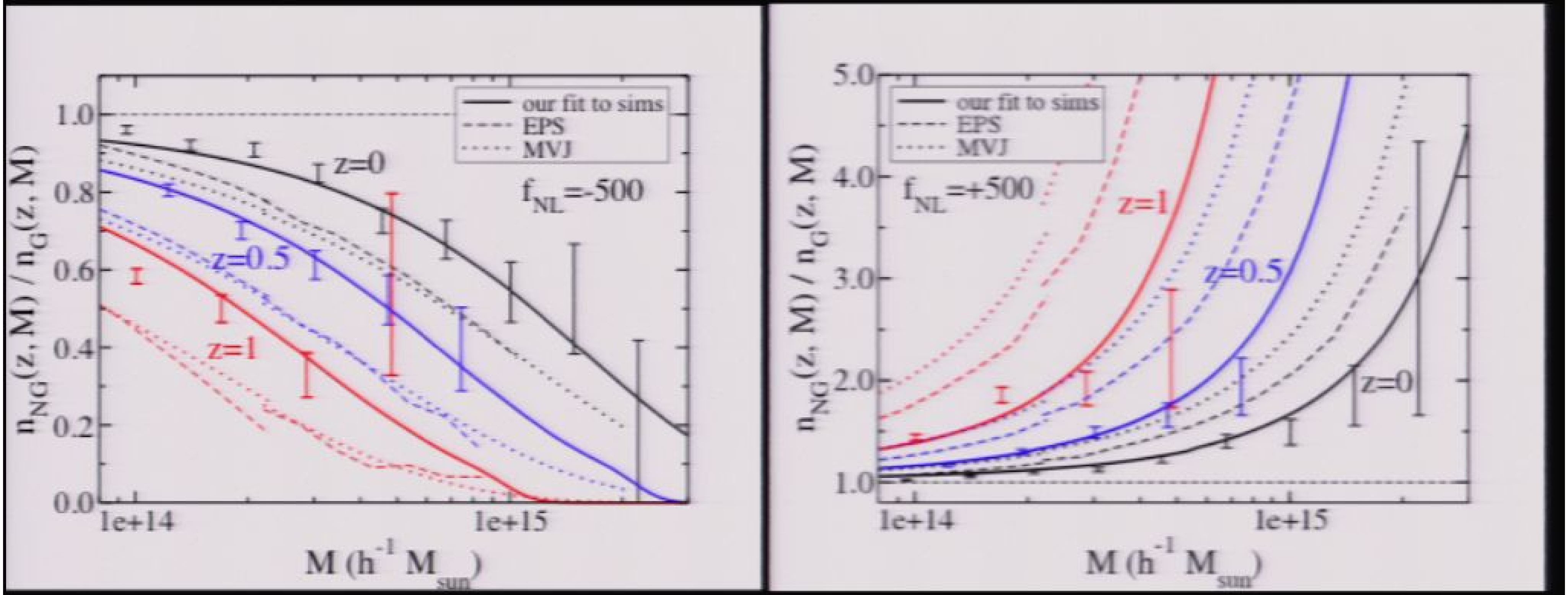
Old fitting functions are discrepant; off by O(100%) wrt truth



Moreover, it is not much harder to run a simulation than evaluate Extended Press-Schechter n(M)!

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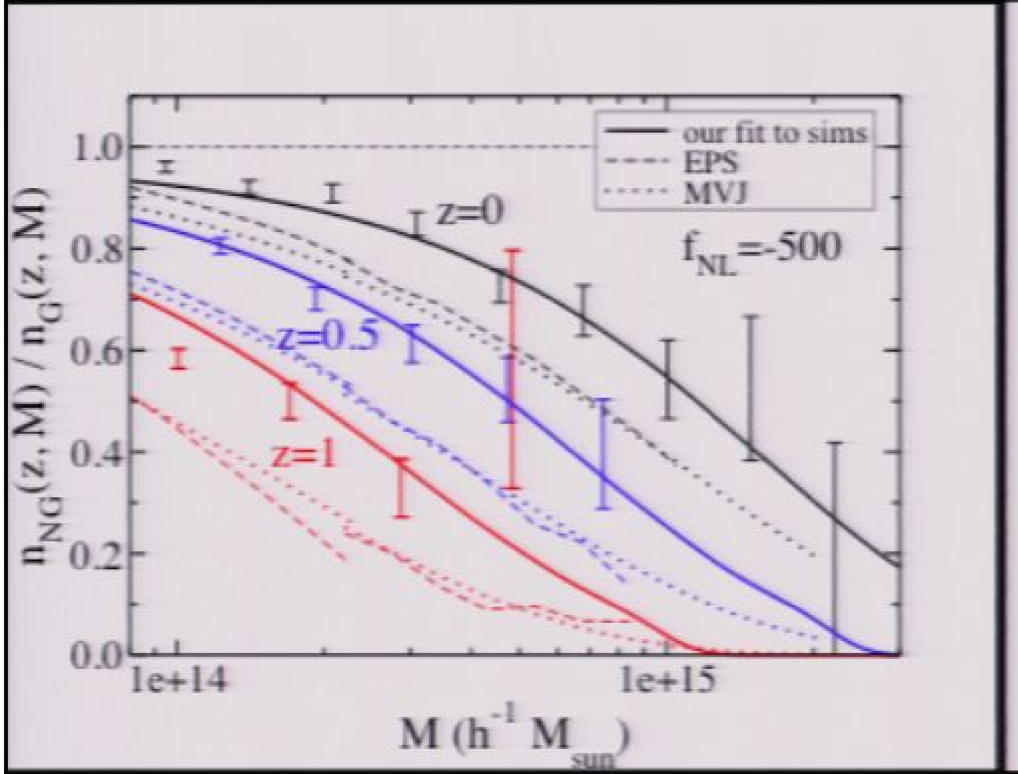

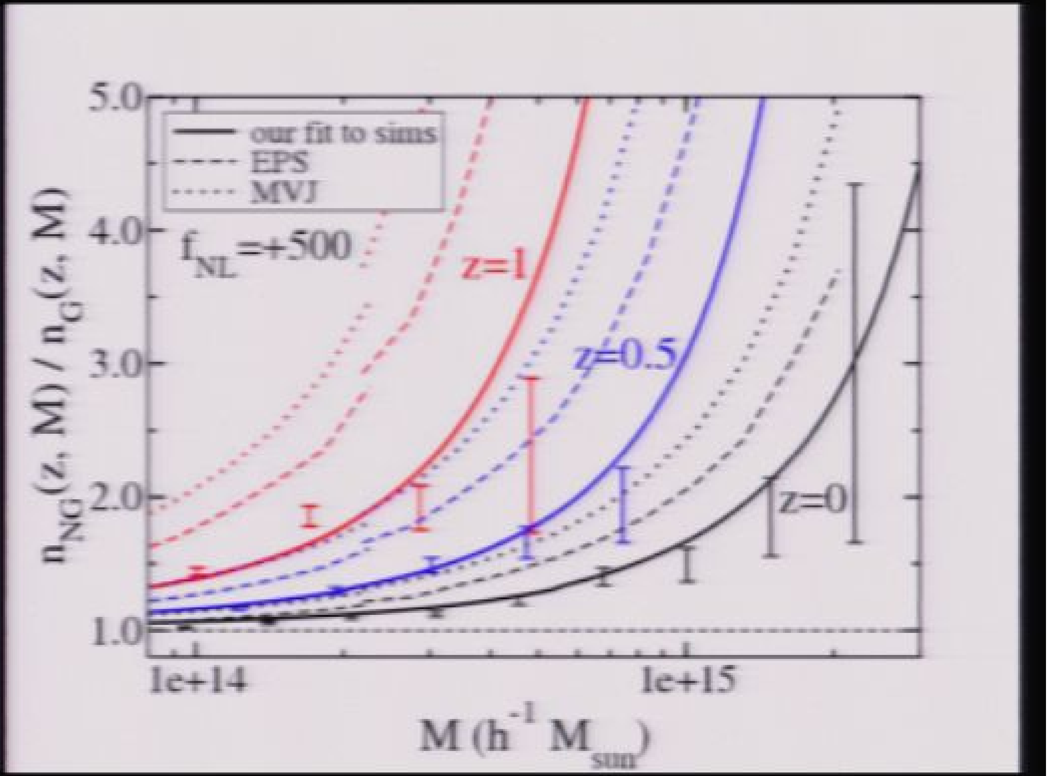

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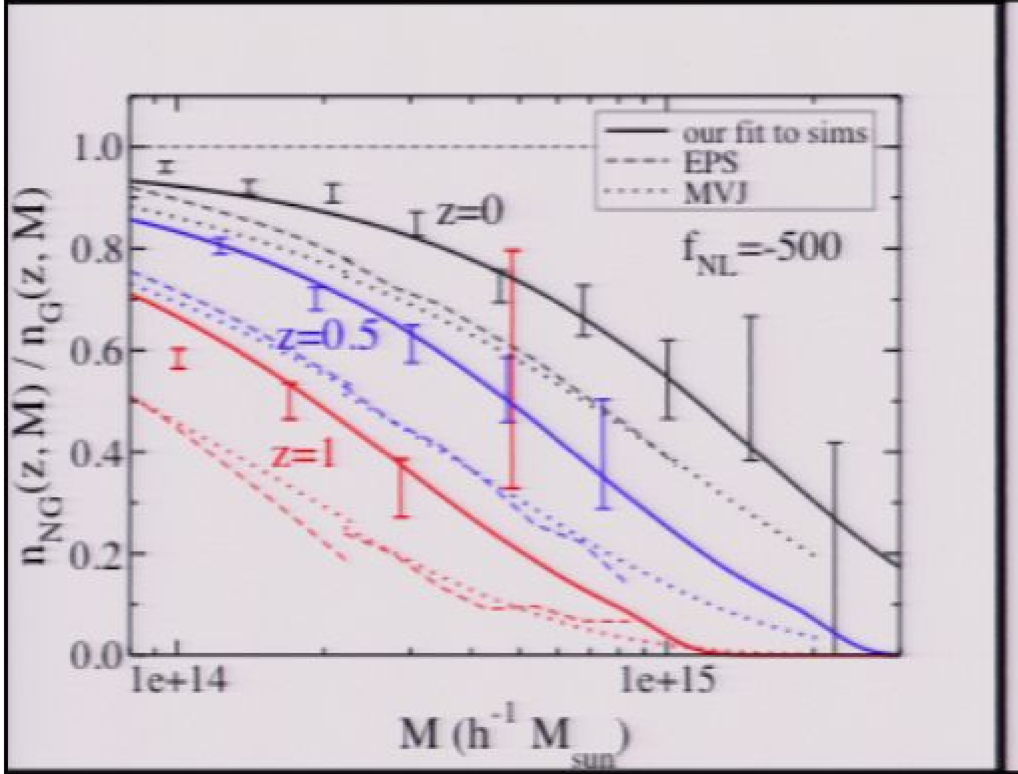

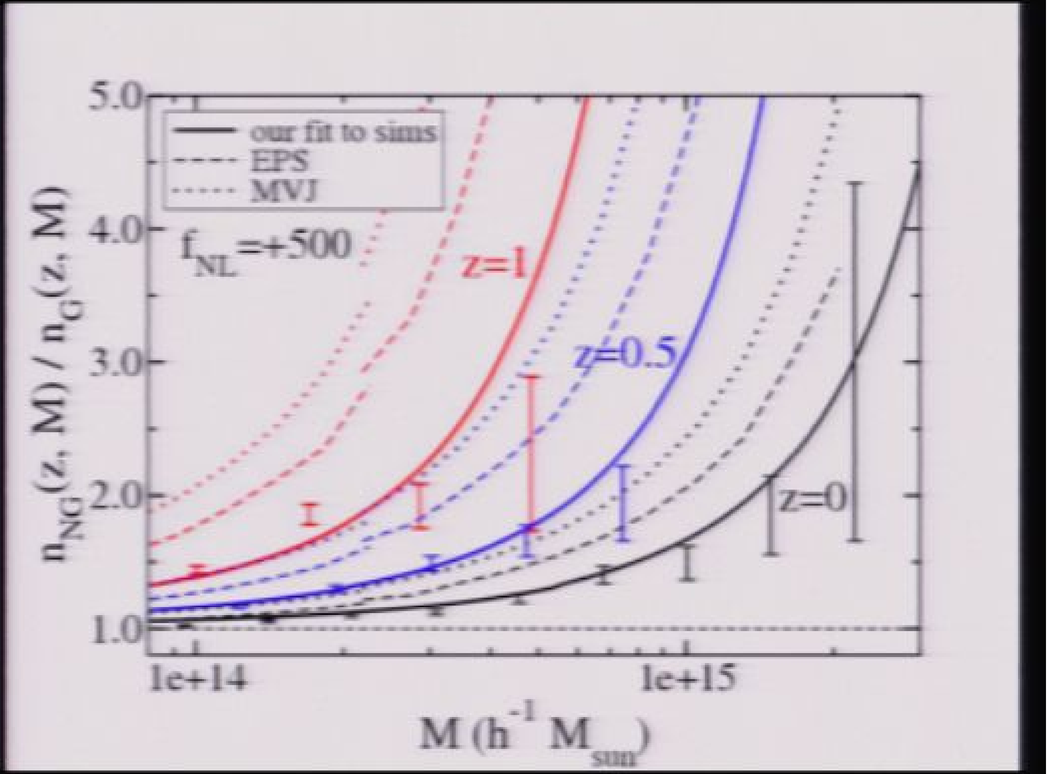

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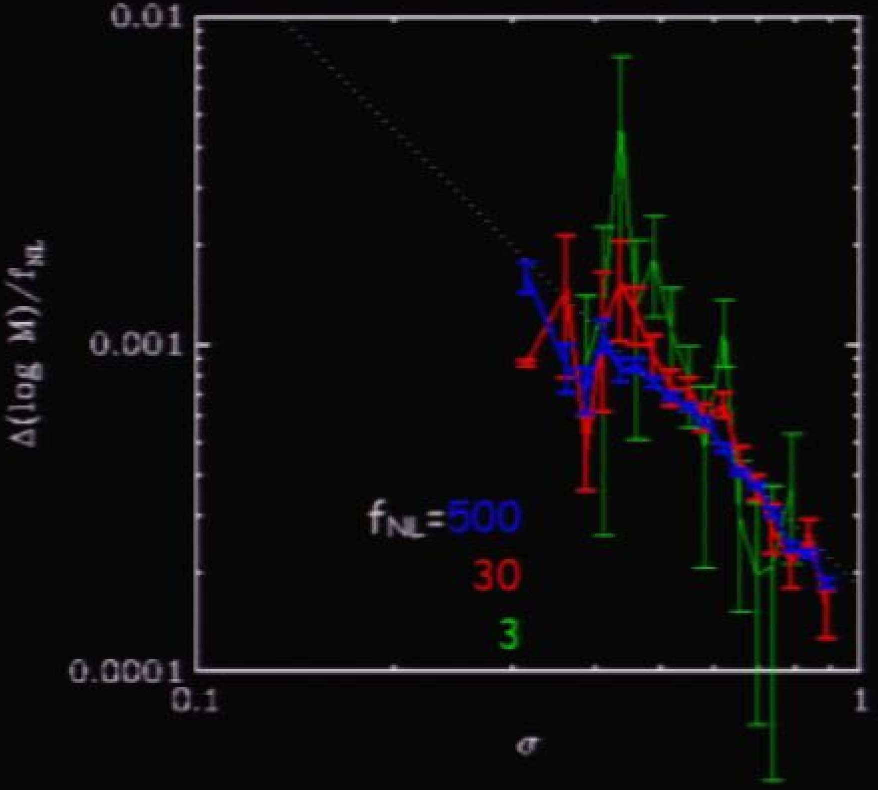

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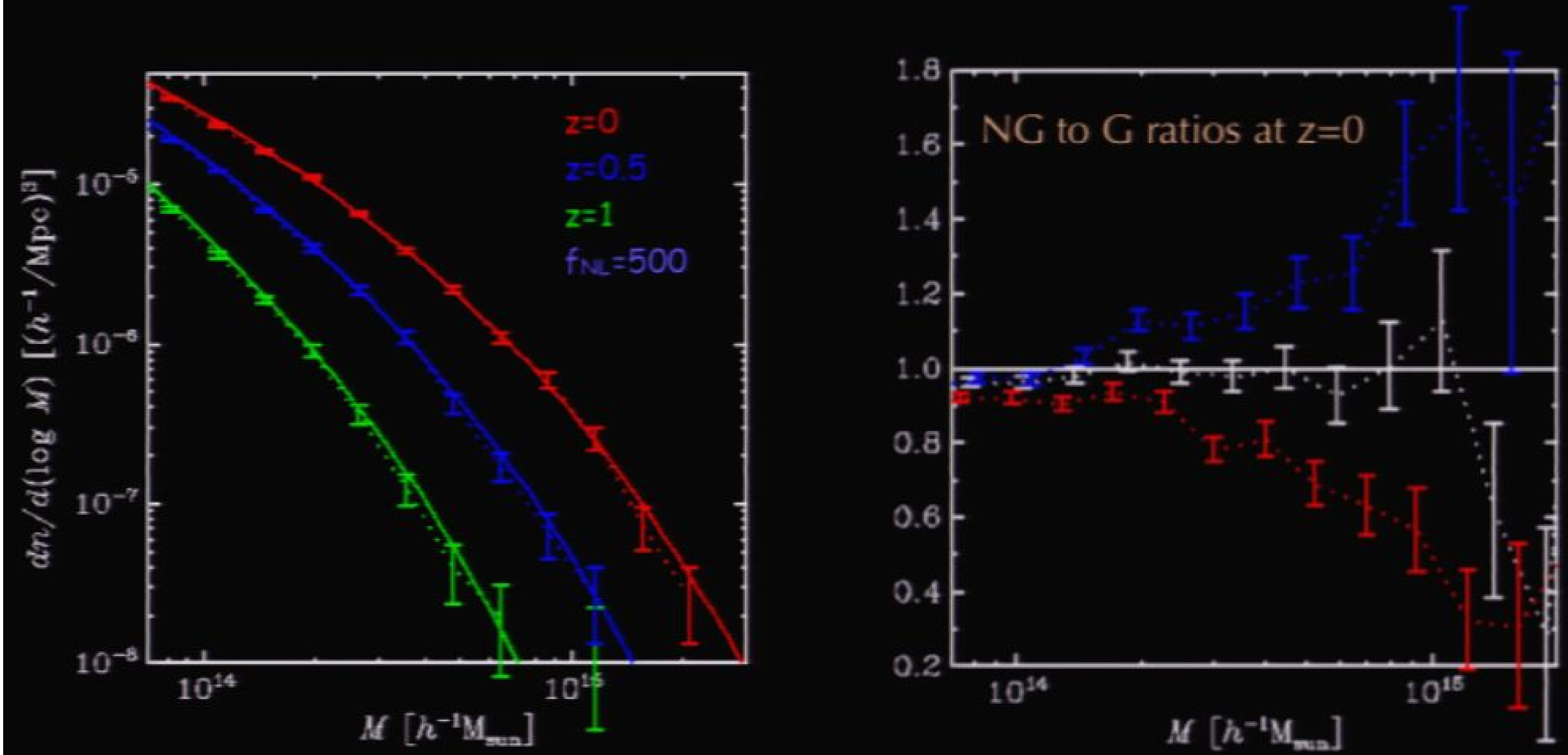

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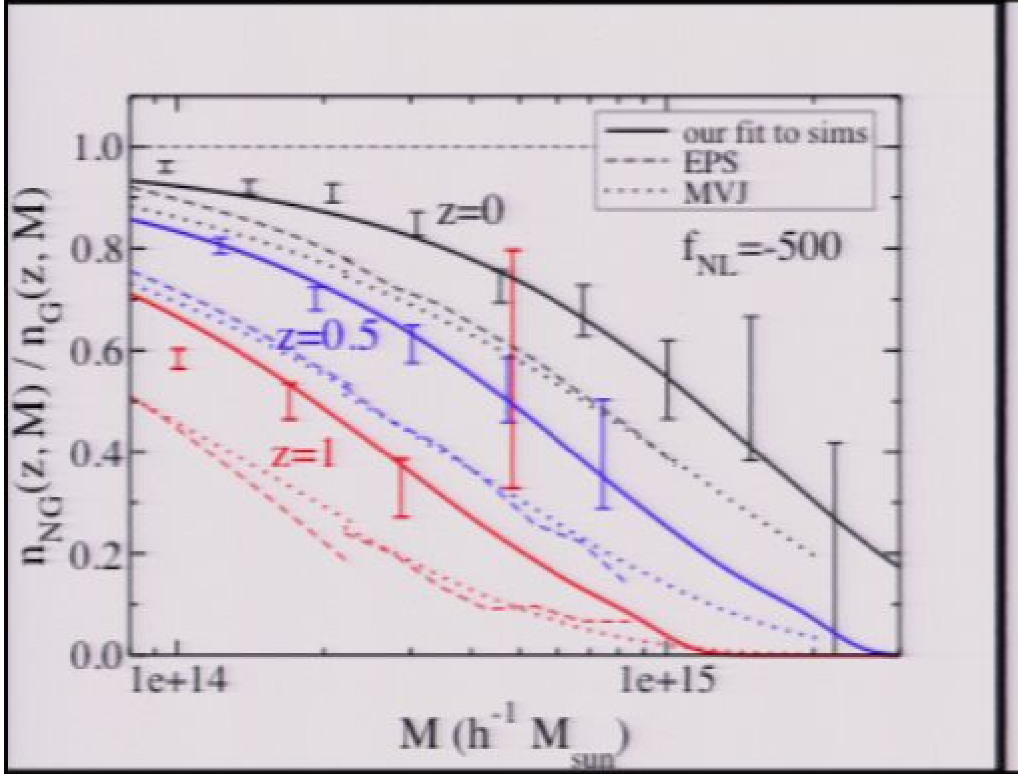

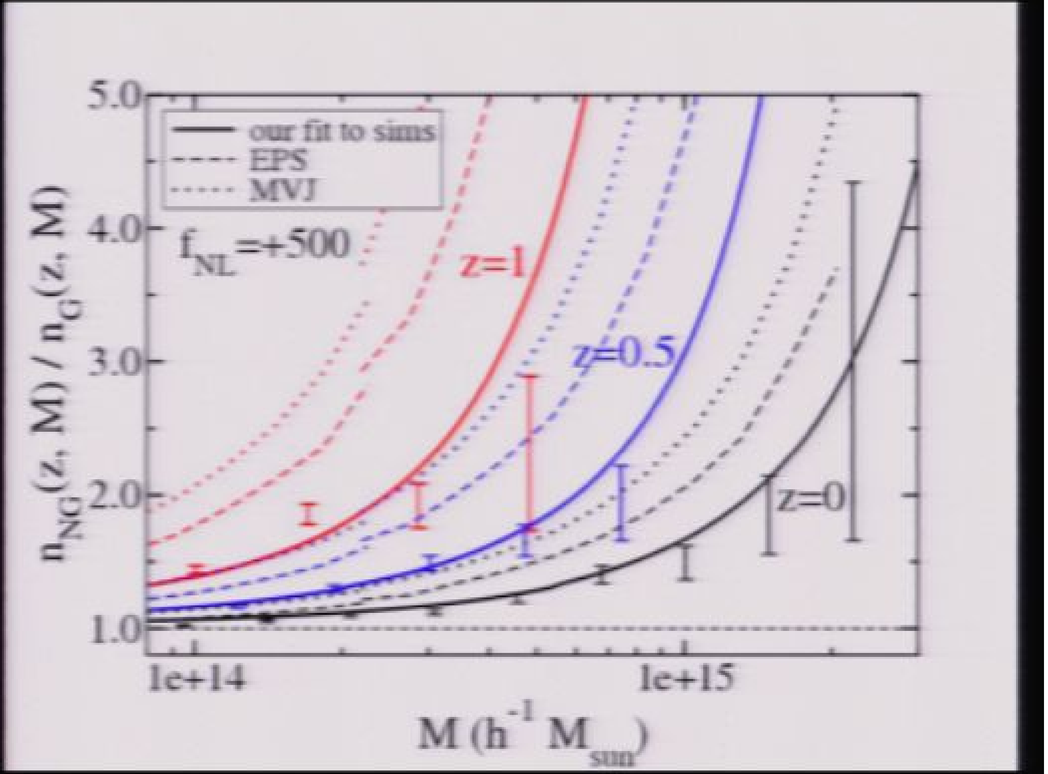

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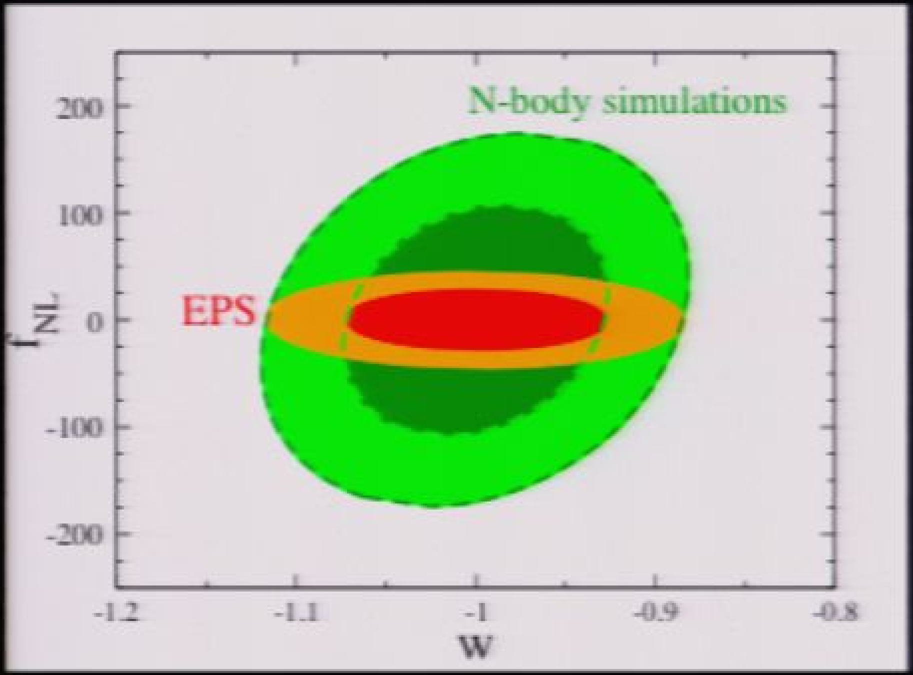
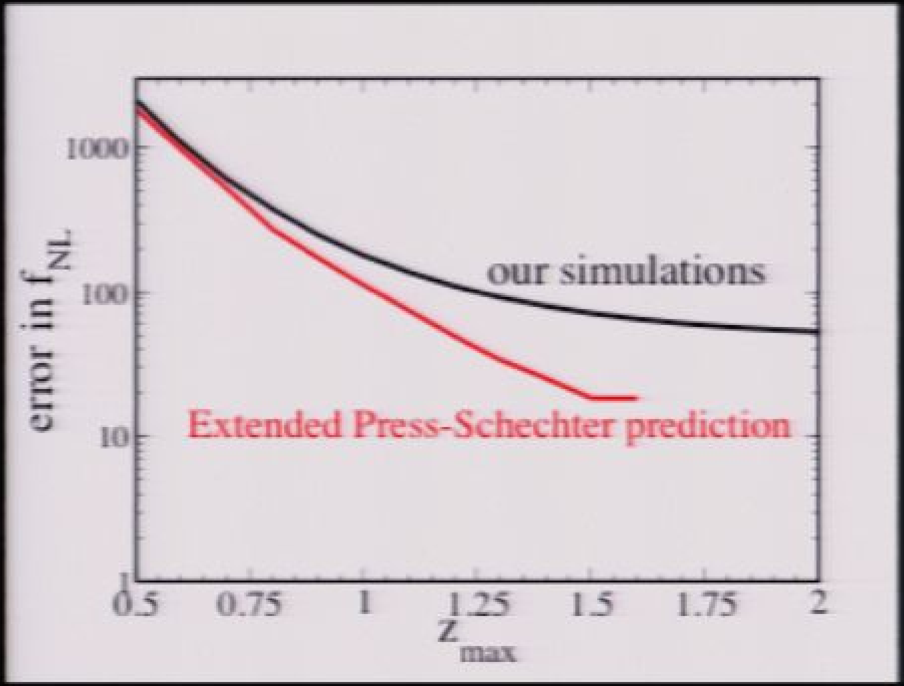
Cosmological constraints - dark energy and NG





SPT-type survey, ~7,000 clusters, 4000 sq.deg., $0.1<z<1.5$
Planck prior

Recall, this is just from the cluster counts;
CMB provides stronger constraints

Comparison to other (numerical) work

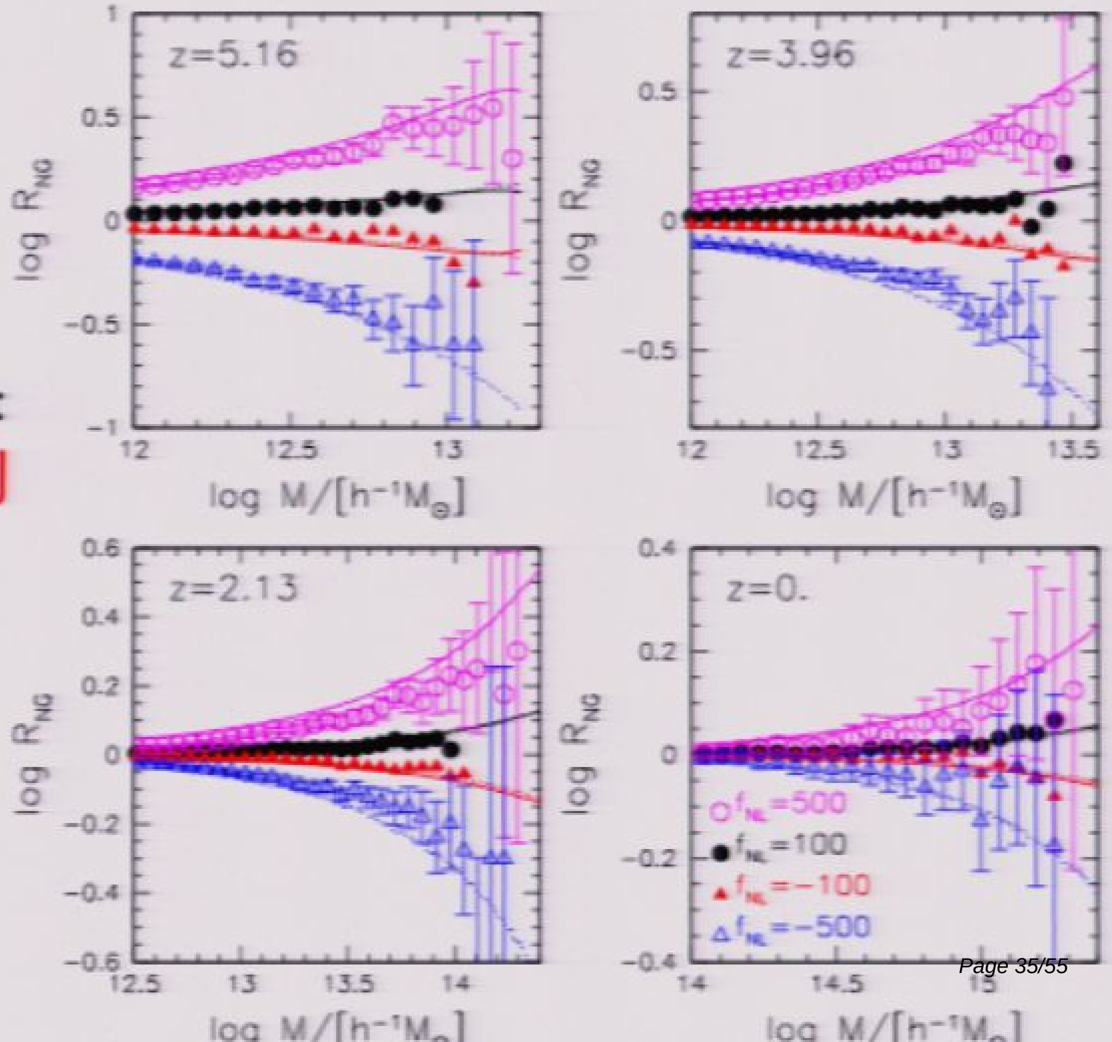
1) Kang, Norberg & Silk (astro-ph/0701131):

claim much *bigger* discrepancy with MVJ,

but: their simulations are 128^3 (insufficient, as they note)

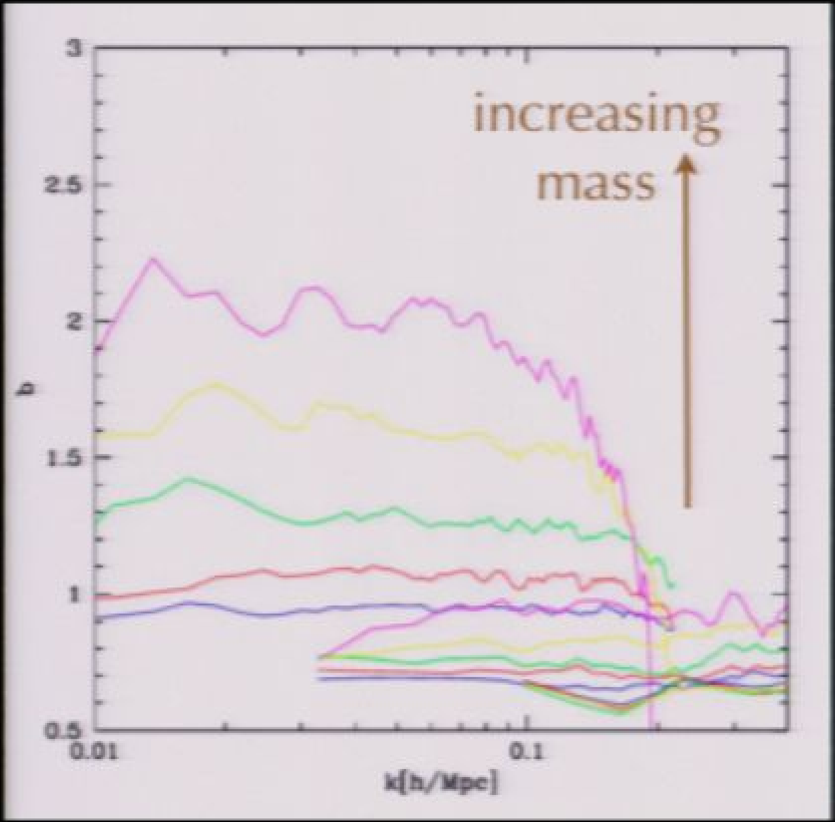
2) Grossi et al (arXiv:0707.2516):

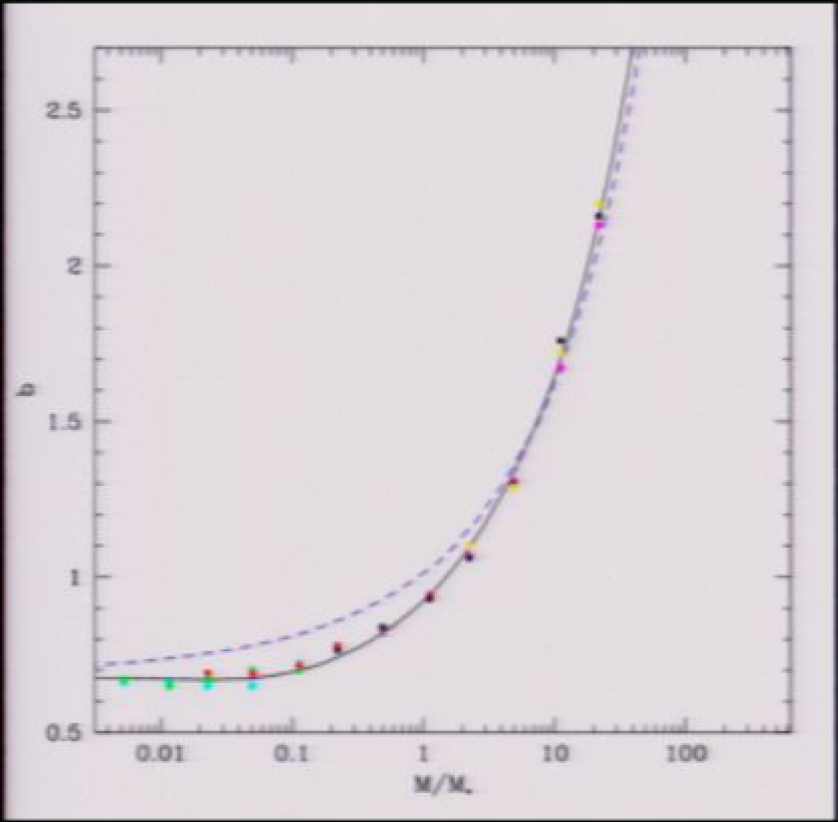
claim perfect agreement with MVJ



Bias of dark matter halos - Gaussian case

$$b \equiv \delta_h / \delta_{\rm DM}$$

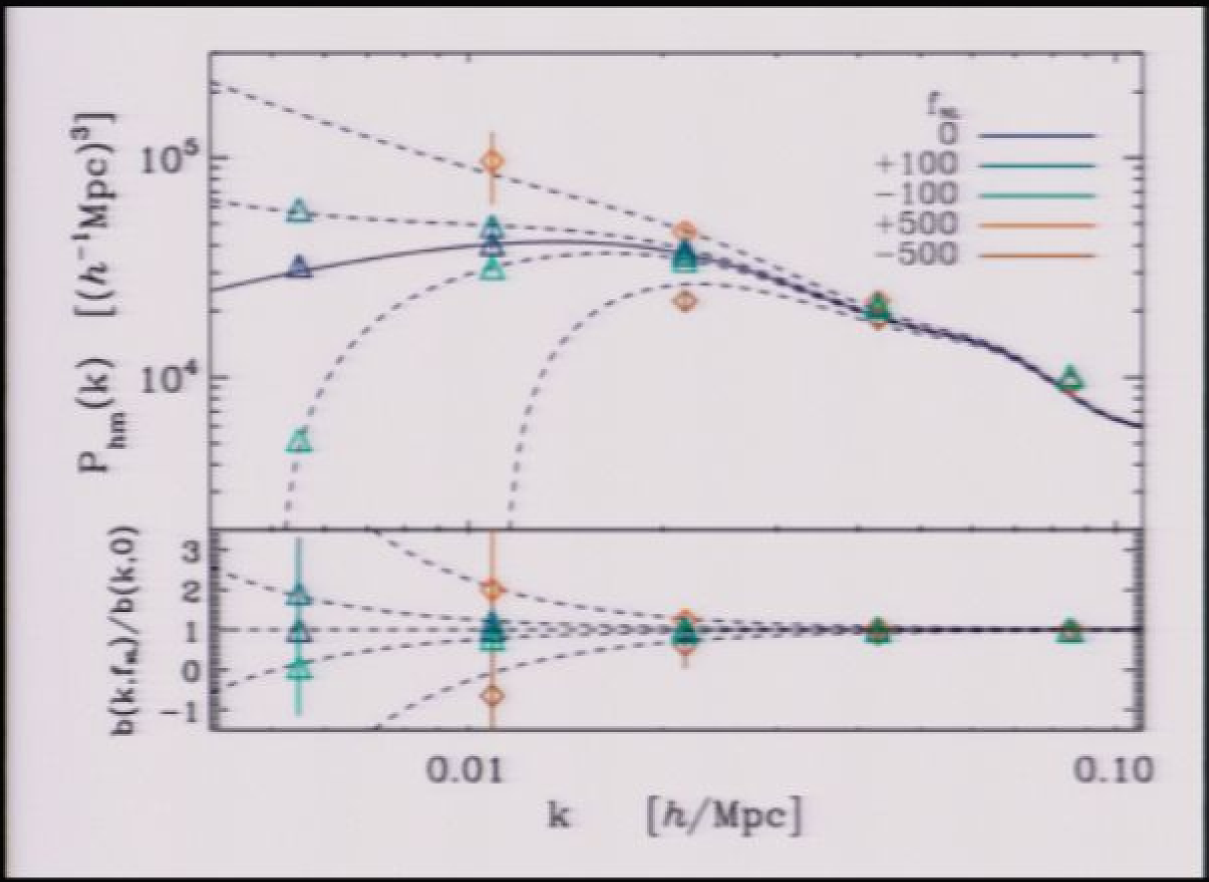




Seljak & Warren 2006

Simulations and theory both say: large-scale bias is scale-independent
(theorem if halo abundance is function of local density)

Scale dependence of NG halo bias!



- Strong scale dependence in linear regime
- Good agreement between theory and simulation
- 512^3 (1024^3) particle simulations with box size 800 (1600) Mpc/h

Halo clustering with NG: Analytic estimates

$$\Phi_{\rm NG} = \phi + f_{\rm NL}(\phi^2 - \langle\phi^2\rangle)$$

Then

$$\nabla^2\Phi_{\rm NG} = \nabla^2\phi + 2f_{\rm NL}\left(\phi\nabla^2\phi + |\nabla\phi|^2\right)$$

We know the statistics of all terms, so we can compute anything, e.g.

Skewness $$S_3 = \frac{\langle\delta_{\rm NG}^3\rangle}{\langle\delta_{\rm NG}^2\rangle^2} = 6f_{\rm NL}\frac{\langle\phi\delta\rangle}{\sigma_\delta^2}$$

And in particular $$\boxed{\delta_{\rm NG} = \delta(1 + 2f_{\rm NL}\phi)}$$

Halo clustering with NG: Analytic estimates

Definition of bias: $\delta_h = b_L \, \delta$

With NG, for peaks: $\delta \rightarrow \delta + 2 f_{\mathrm{NL}} \phi_p \delta_c$

Assuming $\delta_h \rightarrow (b_L + \Delta b(k))\delta$

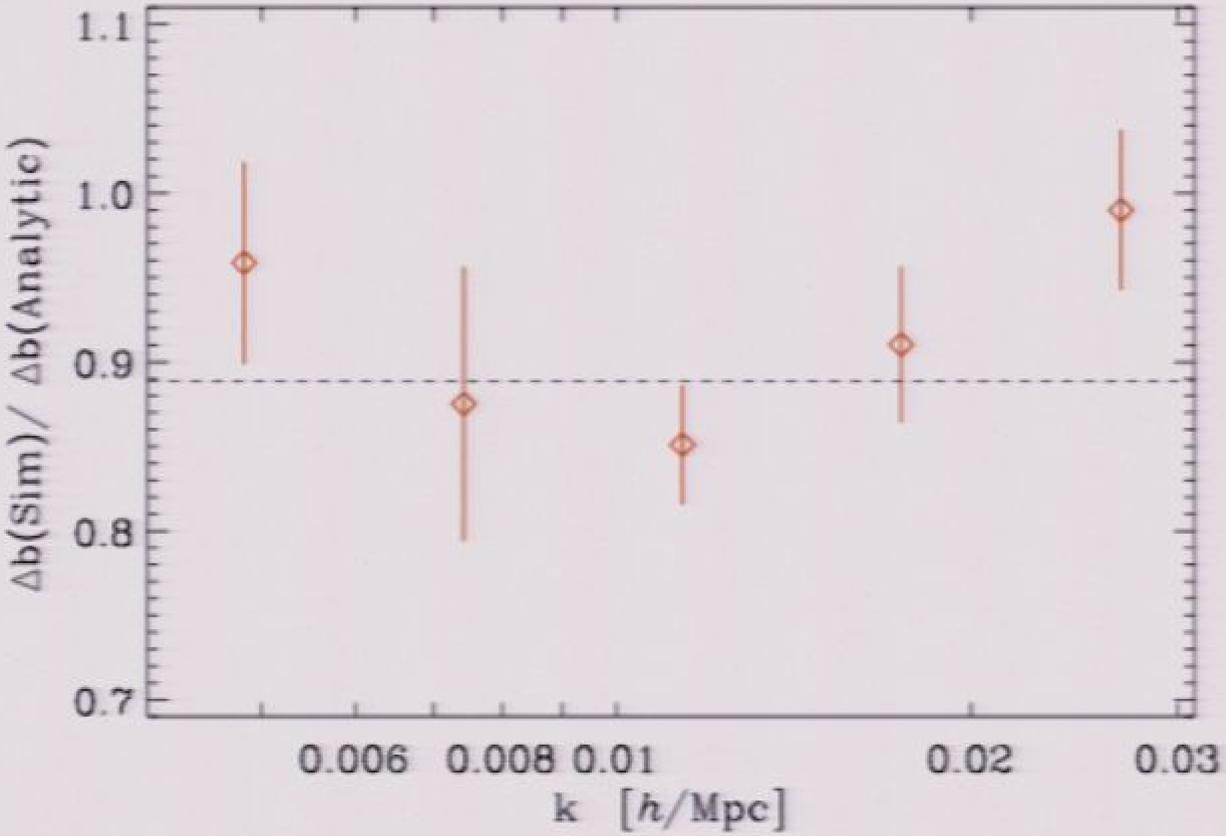
and using Poisson equation it follows that

$$\boxed{\Delta b(k) = 2 b_L \, f_{\mathrm{NL}} \delta_{\mathrm{crit}} \frac{3\Omega_M}{2 a r_H^2 k^2}}$$

Dalal,, Doré, Huterer & Shirokov, arXiv:0710.4560

see also Matarrese & Verde arXiv:0801.4826; Afshordi & Tolley, in prep.

Analytic and numerical results agree



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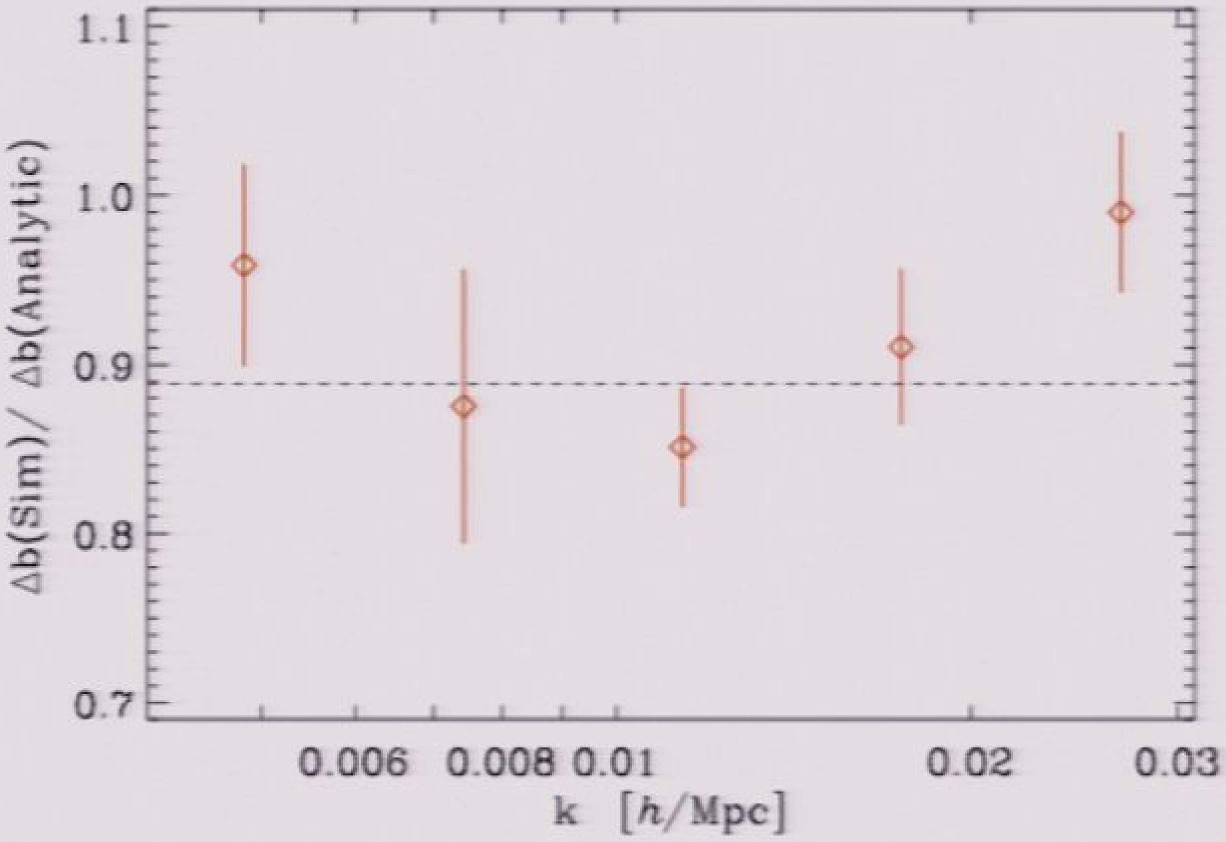


$$\Delta b(k) = 2b_L f_{\mathrm{NL}} \delta_{\mathrm{crit}} \frac{3\Omega_M}{2ar_H^2 k^2}$$

NG from measurements from the b(k) aspect of large-scale structure

- Numerous cosmological probes, such as the baryon acoustic oscillations (BAO) or probes of Integrated Sachs-Wolfe effect (galaxy-CMB cross-corr) can be used to measure b(k)

- The effect (going as k^{-2}) provides a fairly unique signature and an easy target

- Back-of-envelope calculation shows sigma(f_{NL})~10 for a typical LRG survey out to z~0.7 and 1/4 sky

- Current ISW observations should reach sigma(f_{NL})~100; and future ones a factor of ~3 better (see also Afshordi talk)

- Need to estimate these numbers more accurately

Conclusions

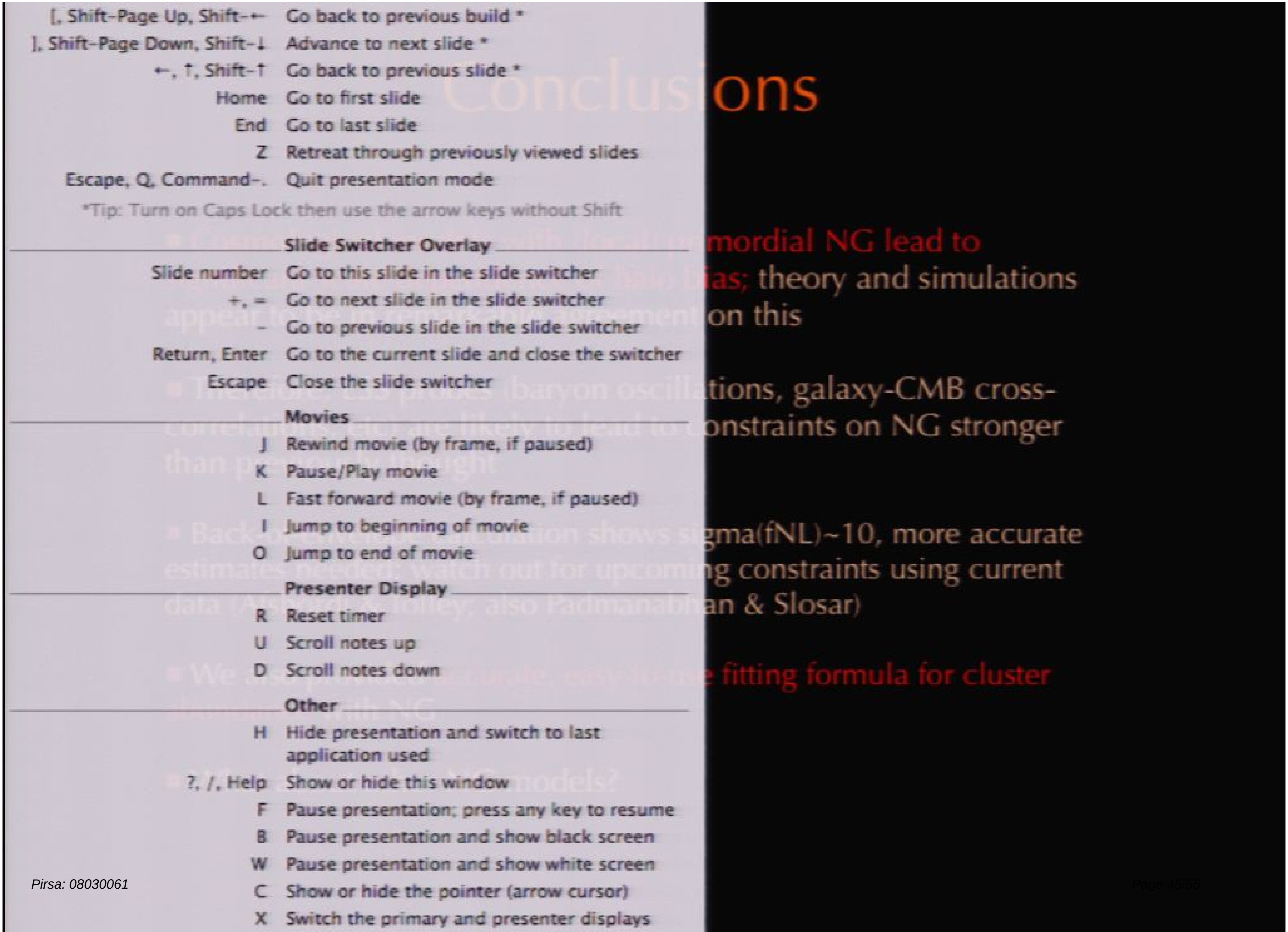
- Cosmological models with (local) primordial NG lead to significant scale dependence of halo bias; theory and simulations appear to be in remarkable agreement on this

- Therefore, LSS probes (baryon oscillations, galaxy-CMB cross-correlations, etc) are likely to lead to constraints on NG stronger than previously thought

- Back-of-envelope calculation shows sigma(fNL)~10, more accurate estimates needed; watch out for upcoming constraints using current data (Afshordi & Tolley; also Padmanabhan & Slosar)

- We also provided accurate, easy-to-use fitting formula for cluster abundance with NG

- What about other NG models?



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Conclusions

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measurements from the large-scale structure

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Halo clustering with NG: Analytic estimates

$$\Phi_{\rm NG} = \phi + f_{\rm NL}(\phi^2 - \langle\phi^2\rangle)$$

Then

$$\nabla^2\Phi_{\rm NG} = \nabla^2\phi + 2f_{\rm NL}\left(\phi\nabla^2\phi + |\nabla\phi|^2\right)$$

We know the statistics of all terms, so we can compute anything, e.g.

Skewness $$S_3 = \frac{\langle\delta_{\rm NG}^3\rangle}{\langle\delta_{\rm NG}^2\rangle^2} = 6f_{\rm NL}\frac{\langle\phi\delta\rangle}{\sigma_\delta^2}$$

And in particular $$\boxed{\delta_{\rm NG} = \delta(1 + 2f_{\rm NL}\phi)}$$

Comparison to other (numerical) work

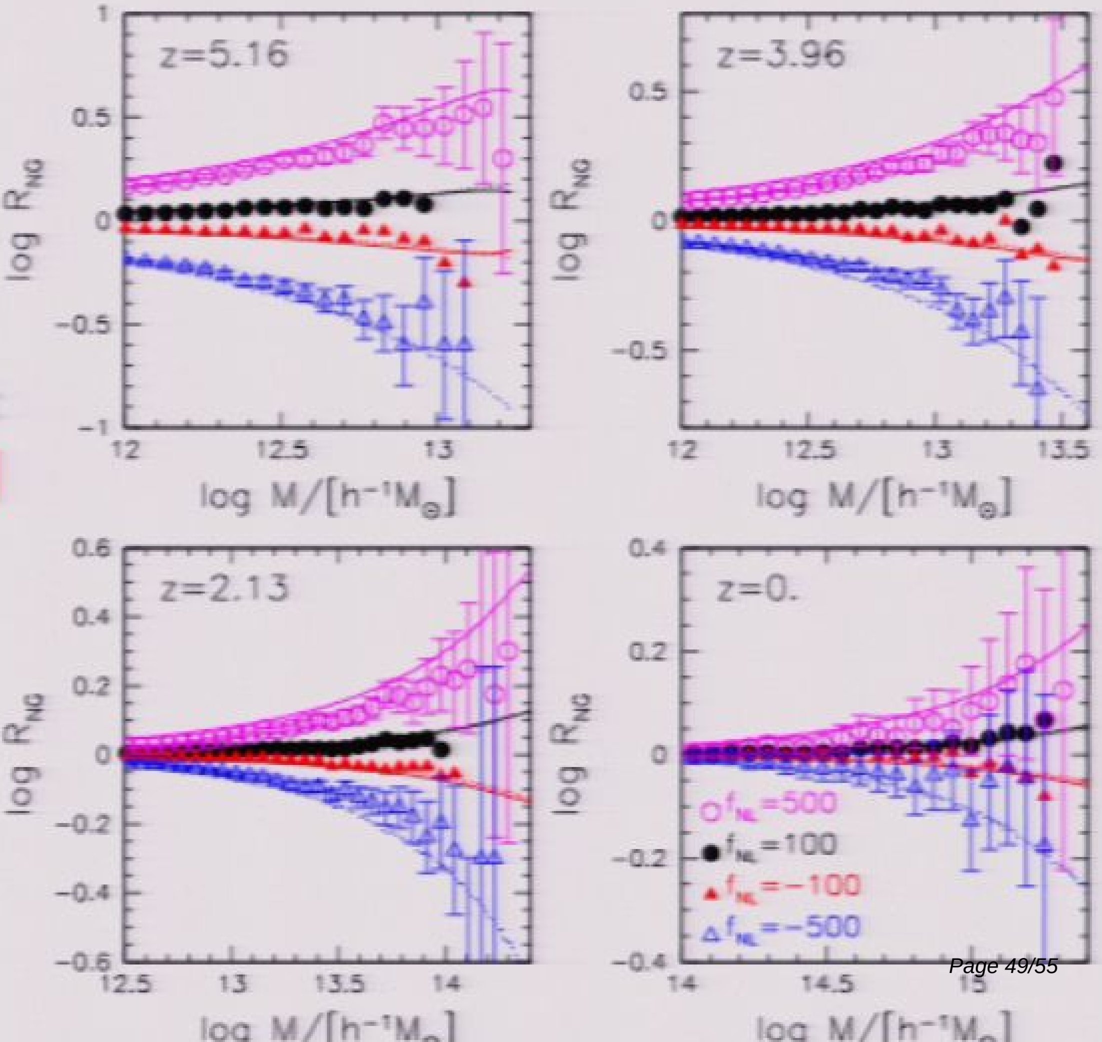
1) Kang, Norberg & Silk (astro-ph/0701131):

claim much *bigger* discrepancy with MVJ,

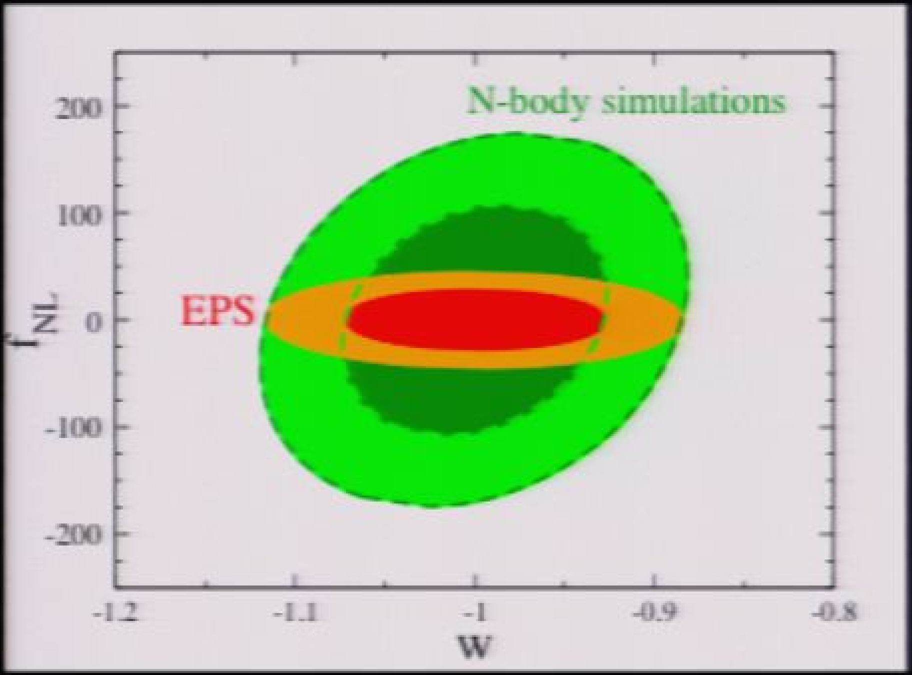
but: their simulations are 128^3 (insufficient, as they note)

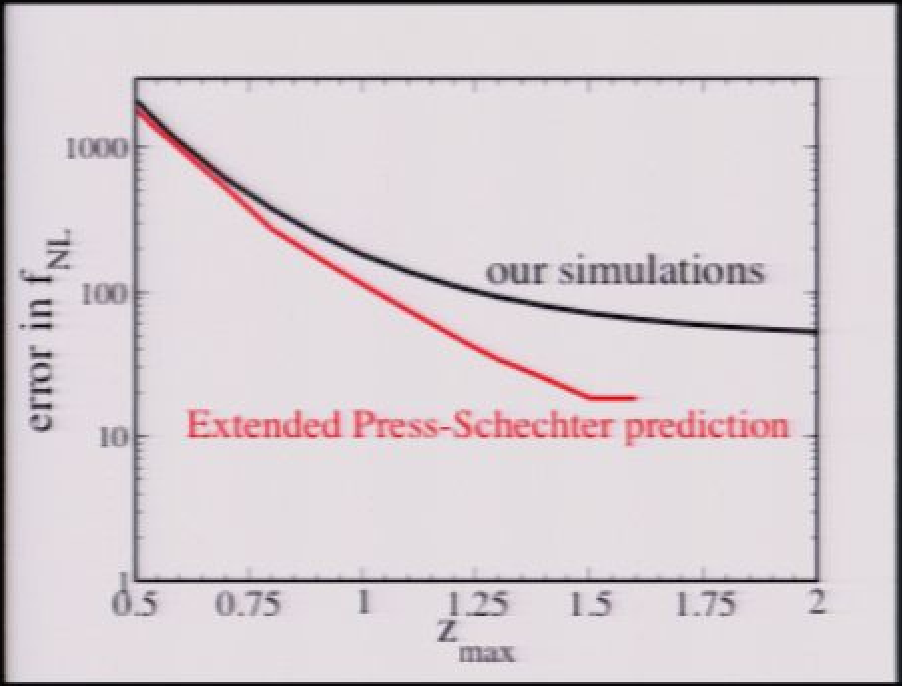
2) Grossi et al (arXiv:0707.2516):

claim perfect agreement with MVJ



Cosmological constraints - dark energy and NG





SPT-type survey, ~7,000 clusters, 4000 sq.deg., 0.1<z<1.5
Planck prior

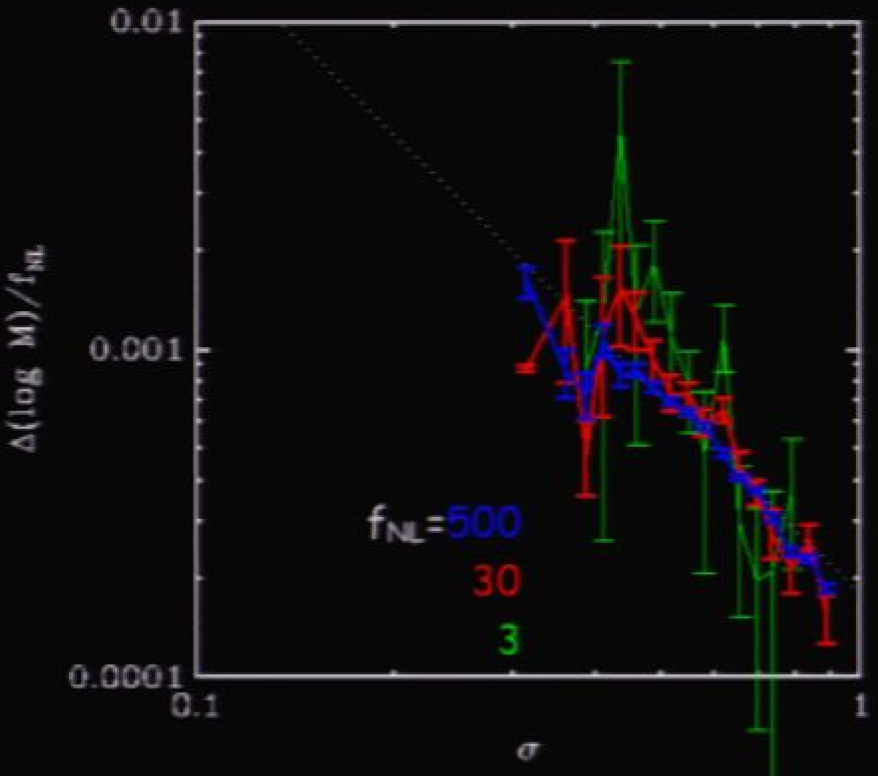
Recall, this is just from the cluster counts;
CMB provides stronger constraints

Towards a fitting function

- If the mapping $M_0 \rightarrow M_f$ is described by a PDF $dP/dM_f(M_0)$, then the non-gaussian mass function is a convolution over the (known) gaussian mass function

$$\boxed{\frac{dN}{dM} = \int \frac{dP(M_f|M_0)}{dM_f}\frac{dN}{dM_0}dM_0}$$

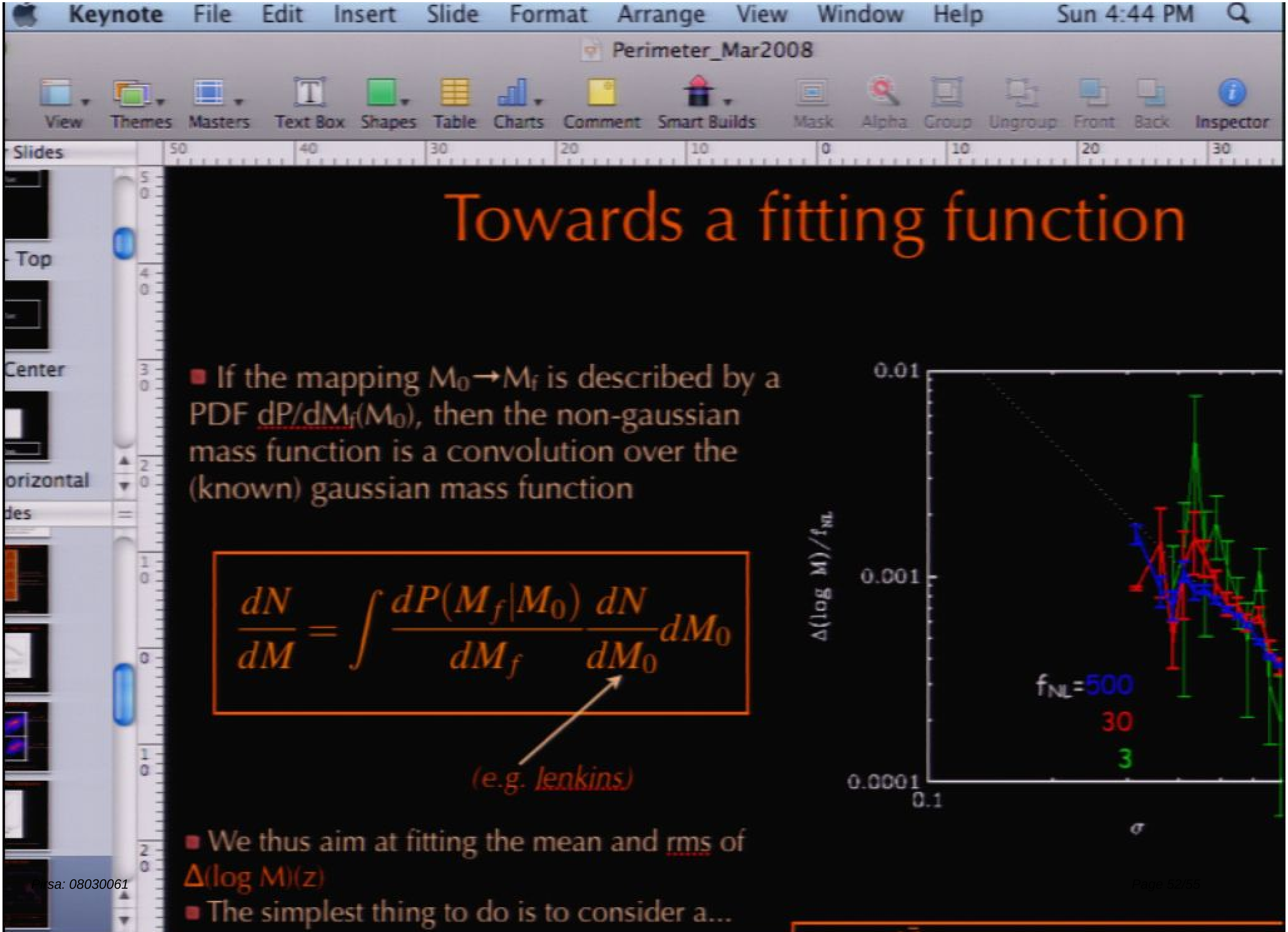
(e.g. Jenkins)



- We thus aim at fitting the mean and rms of Δ(log M)(z)
- The simplest thing to do is to consider a… Gaussian…
- We'd expect the mean of the PDF to be shifted by $\Delta(\log M) \approx f_{NL}$
- We find that a good fit is given by

$$\left[\frac{\bar{M}_f}{M_0}\right] - 1 = 6.\ 10^{-5} f_{NL}\sigma_8\ \sigma(M_0,z)^{-2}$$

$$\sigma\left(\left[\frac{\bar{M}_f}{M_0}\right] - 1\right) = 0.012\ (f_{NL}\sigma_8)^{0.4}\ \sigma(M_0,z)^{-0.5}$$



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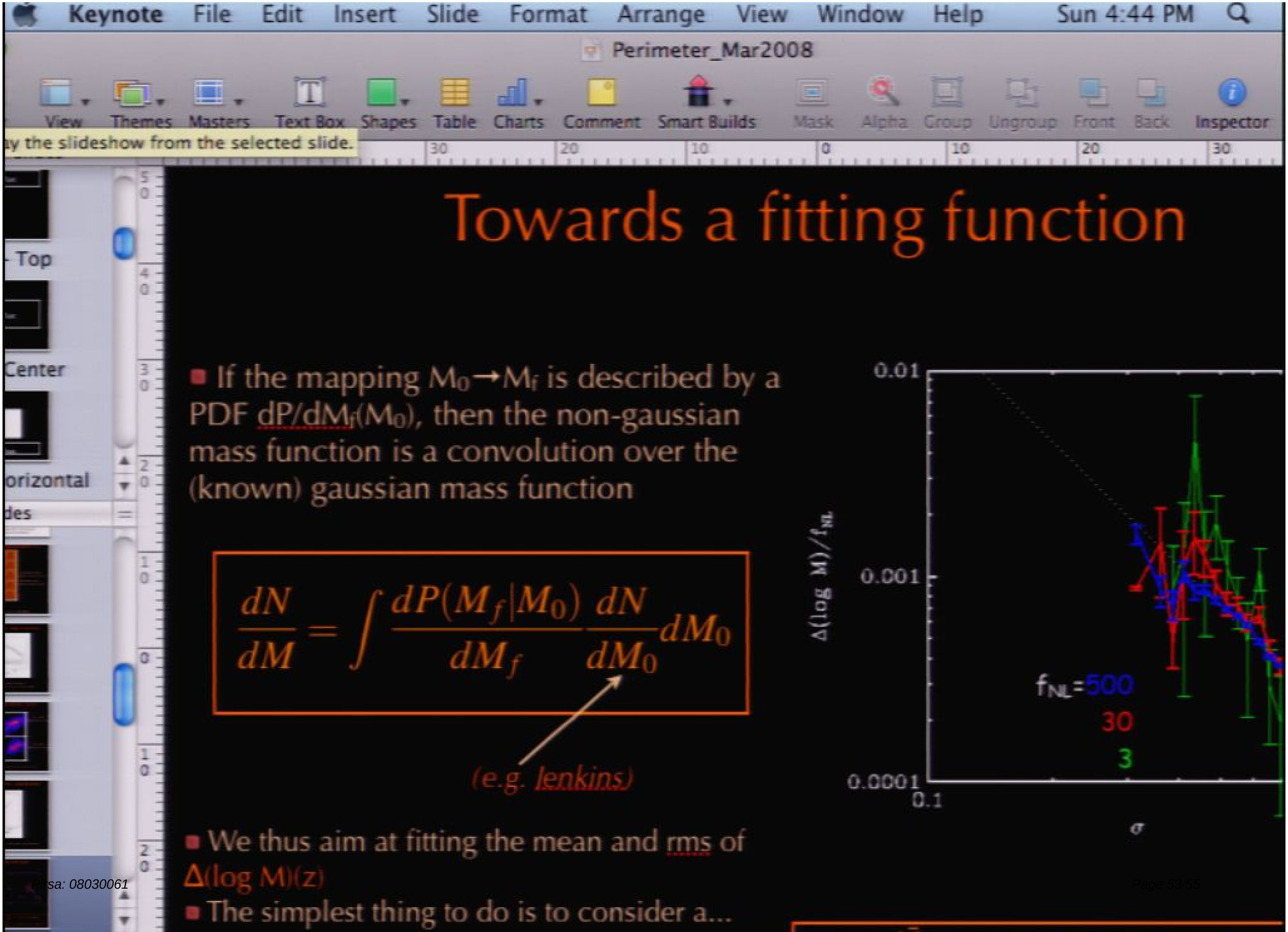

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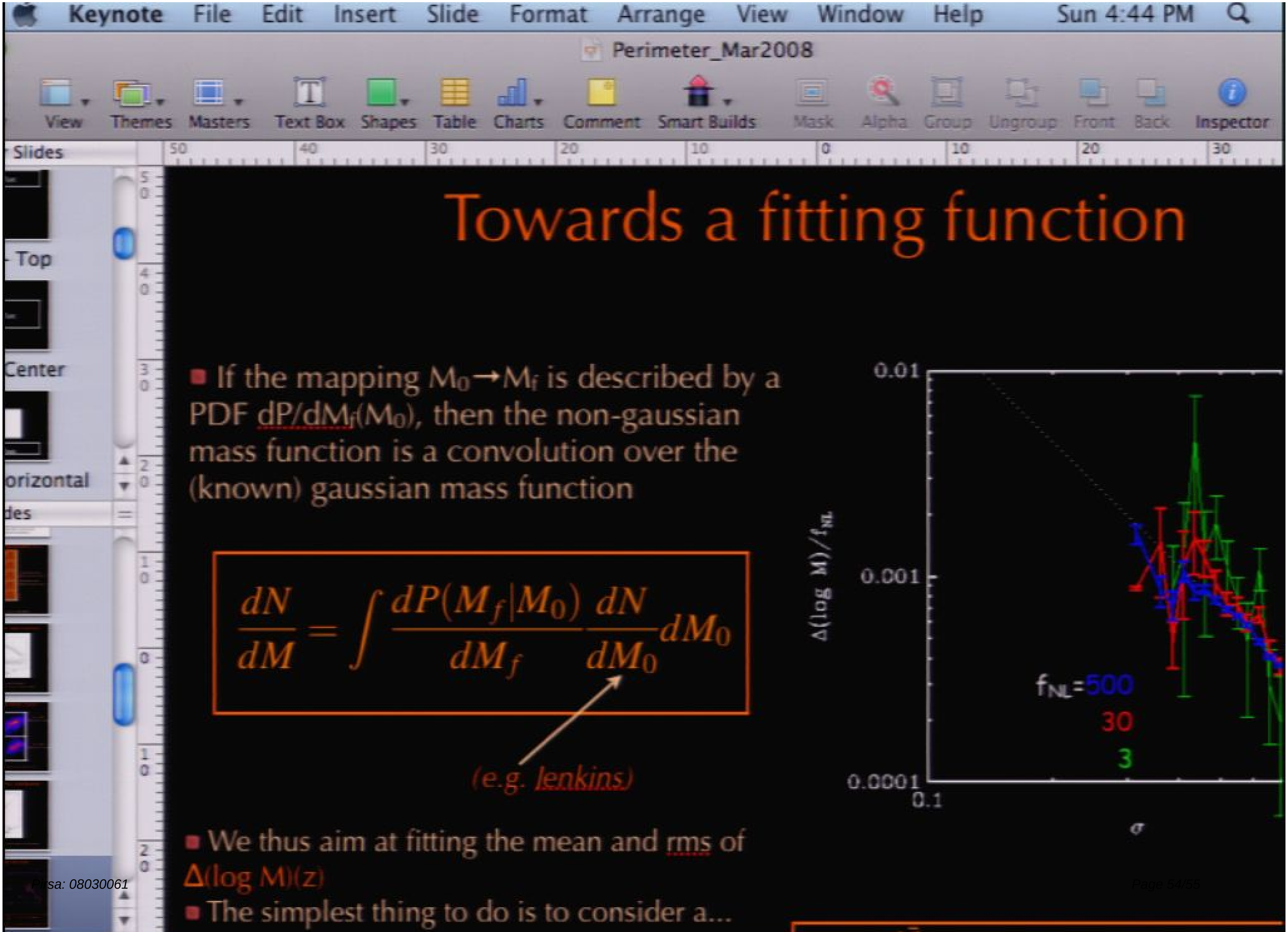

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No Signal
VGA-1