Extragalactic γ-ray signal from dark matter annihilation: a power spectrum perspective

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MNRAS **421**, L87 (2012) and *in preparation*

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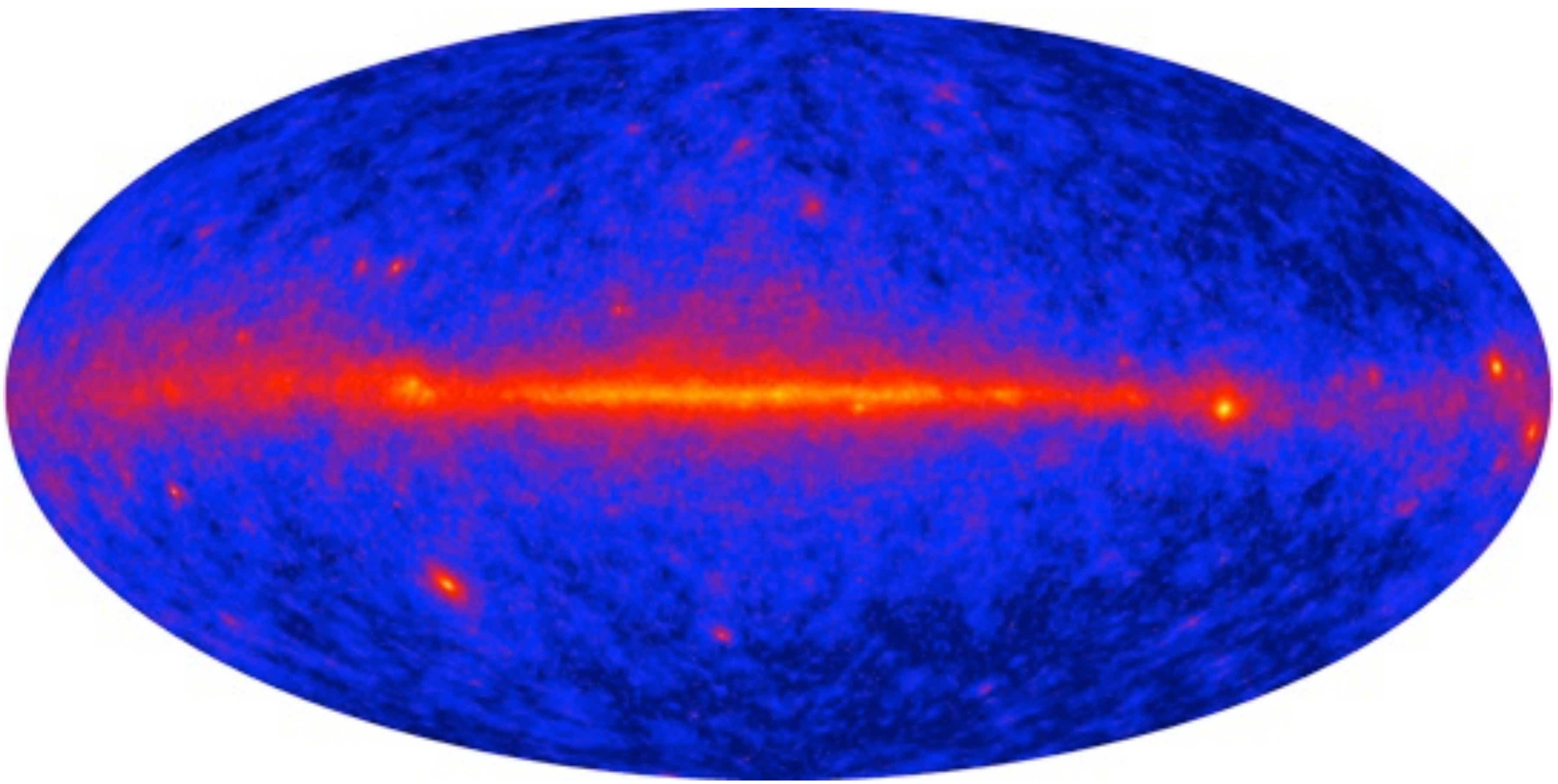
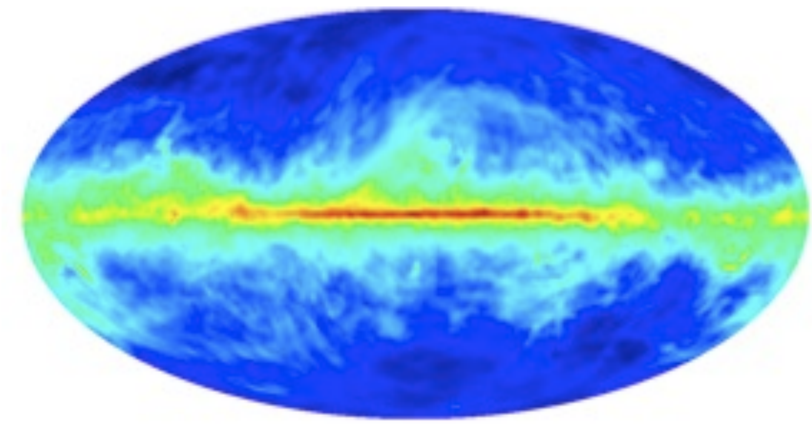
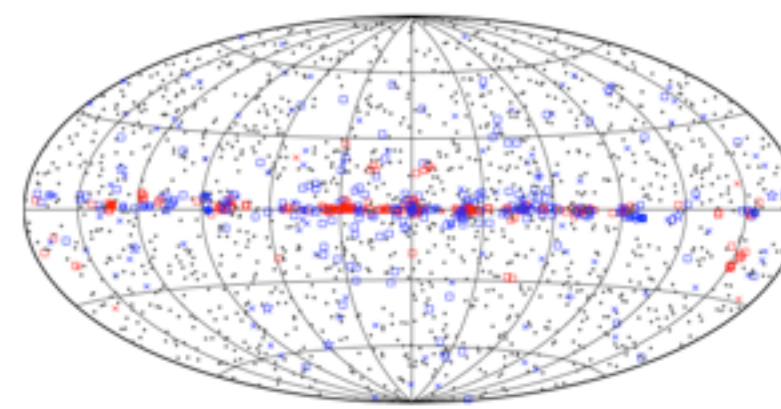
ICTP

The γ-ray sky

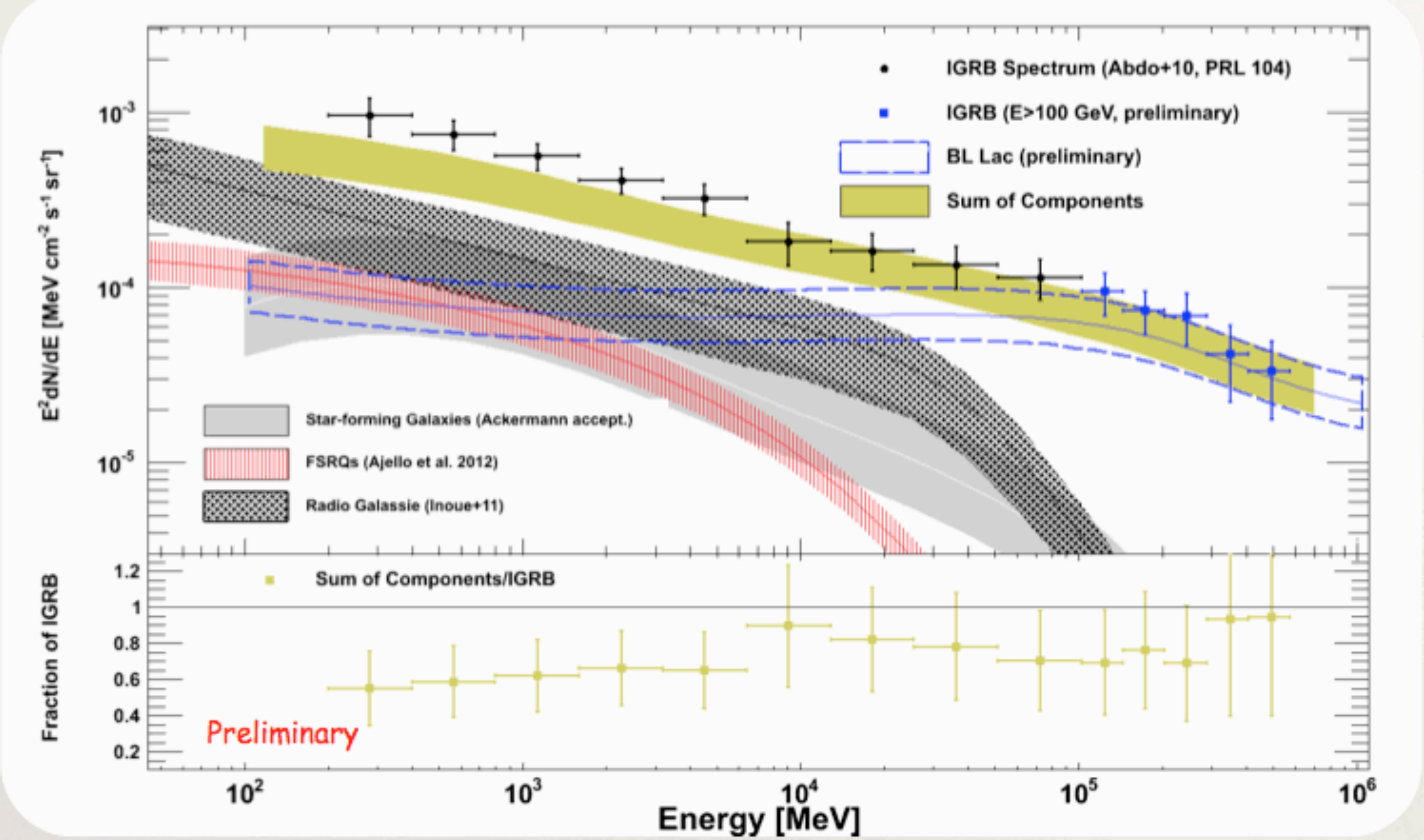
The **Extra Galactic, diffuse γ-ray signal** is inferred from a multicomponent fit to Fermi-LAT data.







Extragalactic diffuse emission: DM contribution?



Sources:

- ***unresolved extragalactic sources***: blazars, star forming and star burst galaxies ...
- ***Dark Matter annihilation*** *in all halos at all red-shifts can contribute*

Extragalactic γ-rays from annihilating DM

$$n = \frac{\langle \sigma v \rangle}{2\, m_{DM}^2} \int_V d^3x\, \rho_{DM}^2(\vec{x})$$

# of annihilations per unit volume

$$\frac{d\phi_\gamma}{dE_0} = \frac{1}{8\,\pi} \frac{\langle \sigma v \rangle}{m_{DM}^2} \int dz\, \frac{(1+z)^3}{H(z)} \frac{dN_\gamma[E_0\,(1+z)]}{dE}\, e^{-\tau(z,E_0)}\, \rho^2(z)$$

observed spectrum

geometry

spectrum at emission

attenuation due to pair production on extragalactic background light

DM "interesting properties"

degeneracy

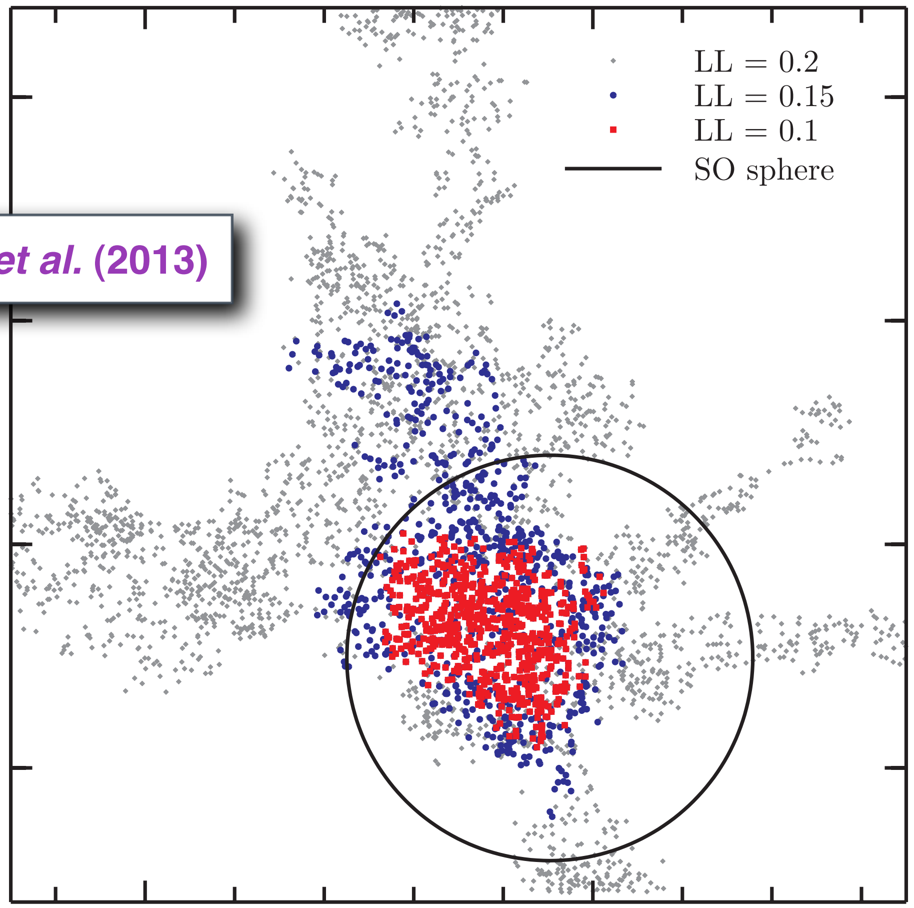
matter density

Ullio *et al.* (2002)

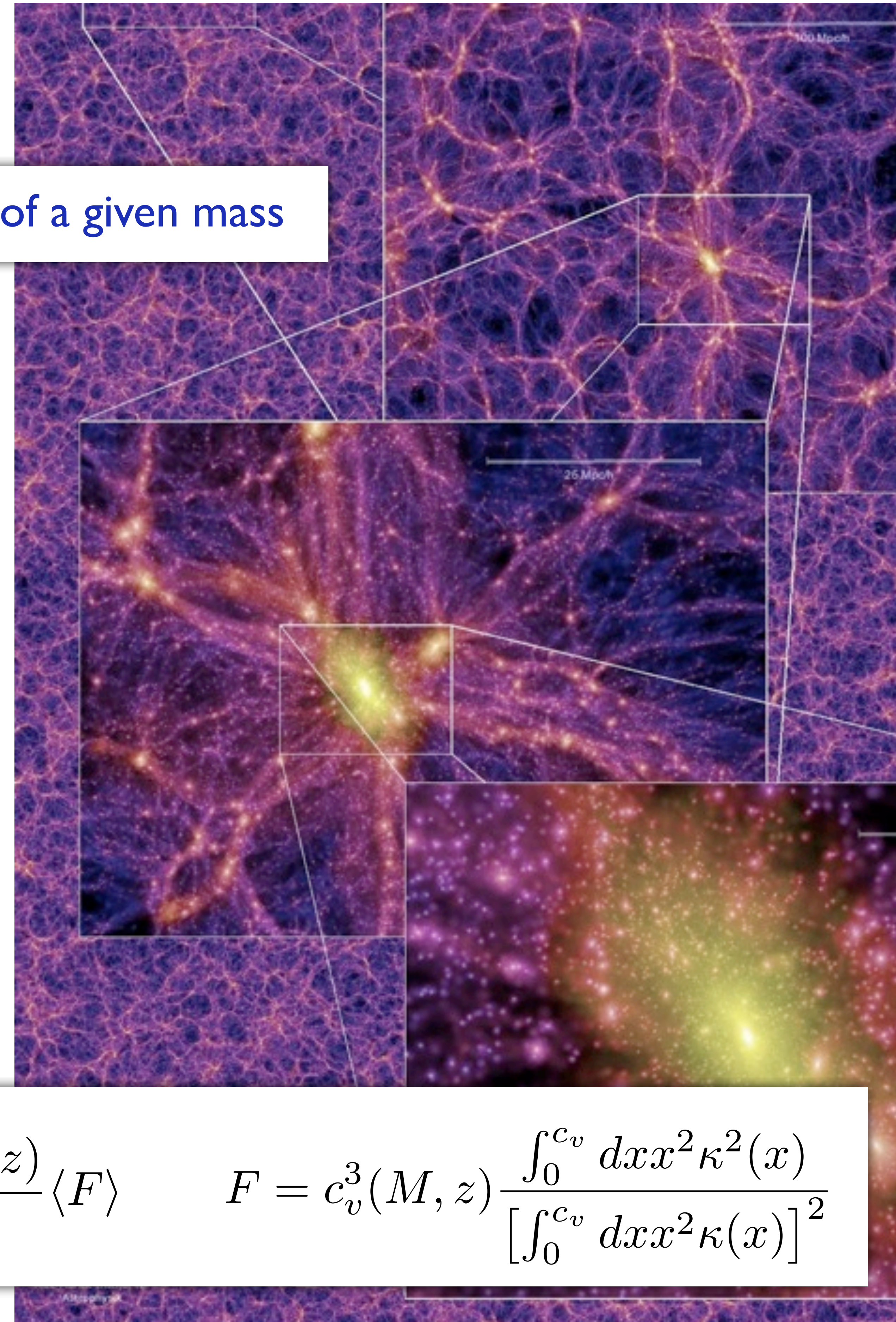
The Halo Model approach

$$\rho(z,\hat{\Omega}) = \bar{\rho}(z)\,\Delta(z,\hat{\Omega})$$

all DM particles belong to a (spherical?) DM *halo* of a given mass



Watson *et al.* (2013)



then have the "flux multipier"

$$\Delta^2(z) \equiv \zeta(z) = \frac{1}{\Omega_m \rho_c} \int_{M_{min}} dM \frac{dn}{dM} M \frac{\Delta_{vir}(z)}{3} \langle F \rangle \qquad F = c_v^3(M,z) \frac{\int_0^{c_v} dx\, x^2 \kappa^2(x)}{\left[\int_0^{c_v} dx\, x^2 \kappa(x)\right]^2}$$

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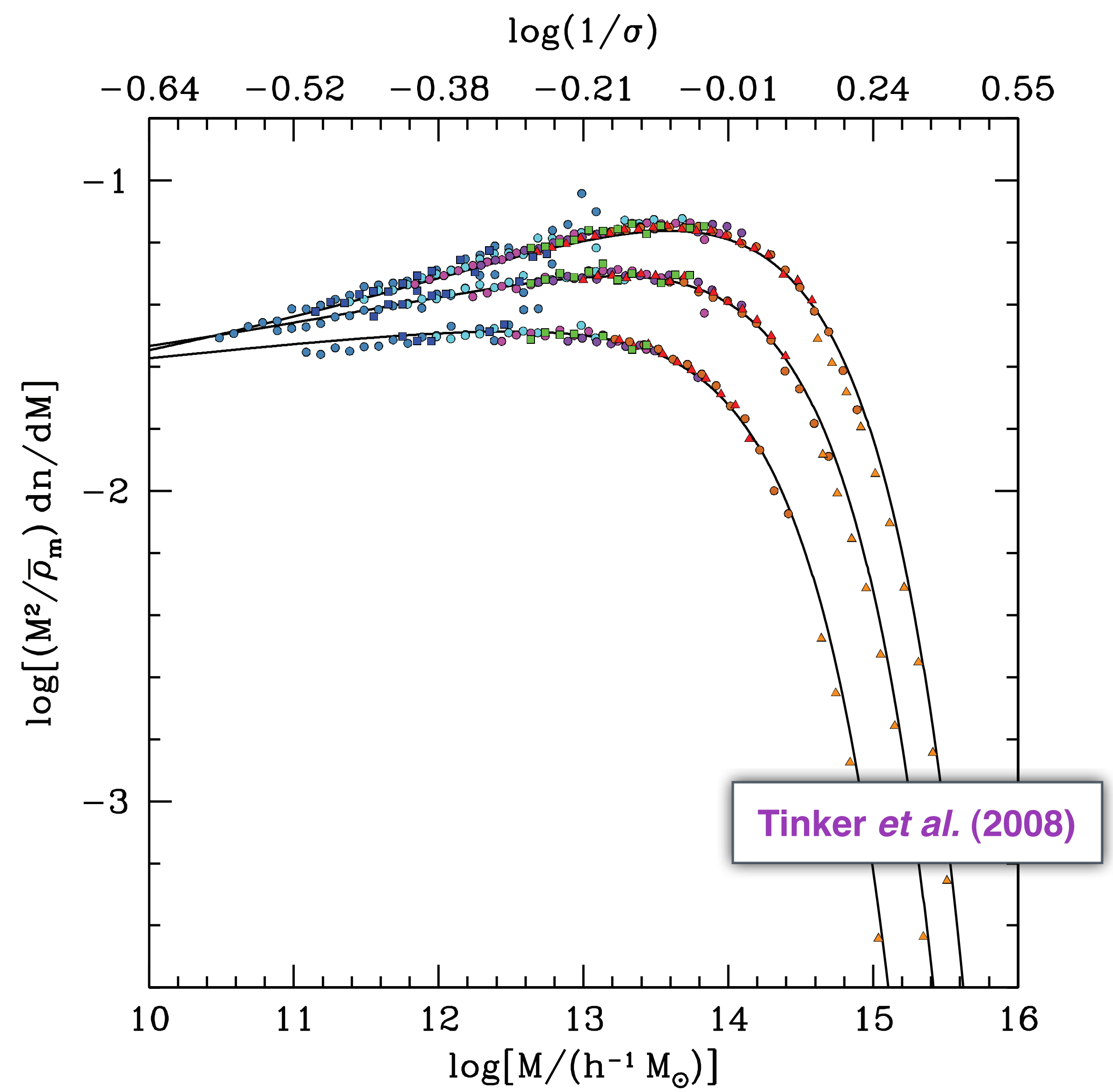
Ingredients:

1. Halos **mass function**



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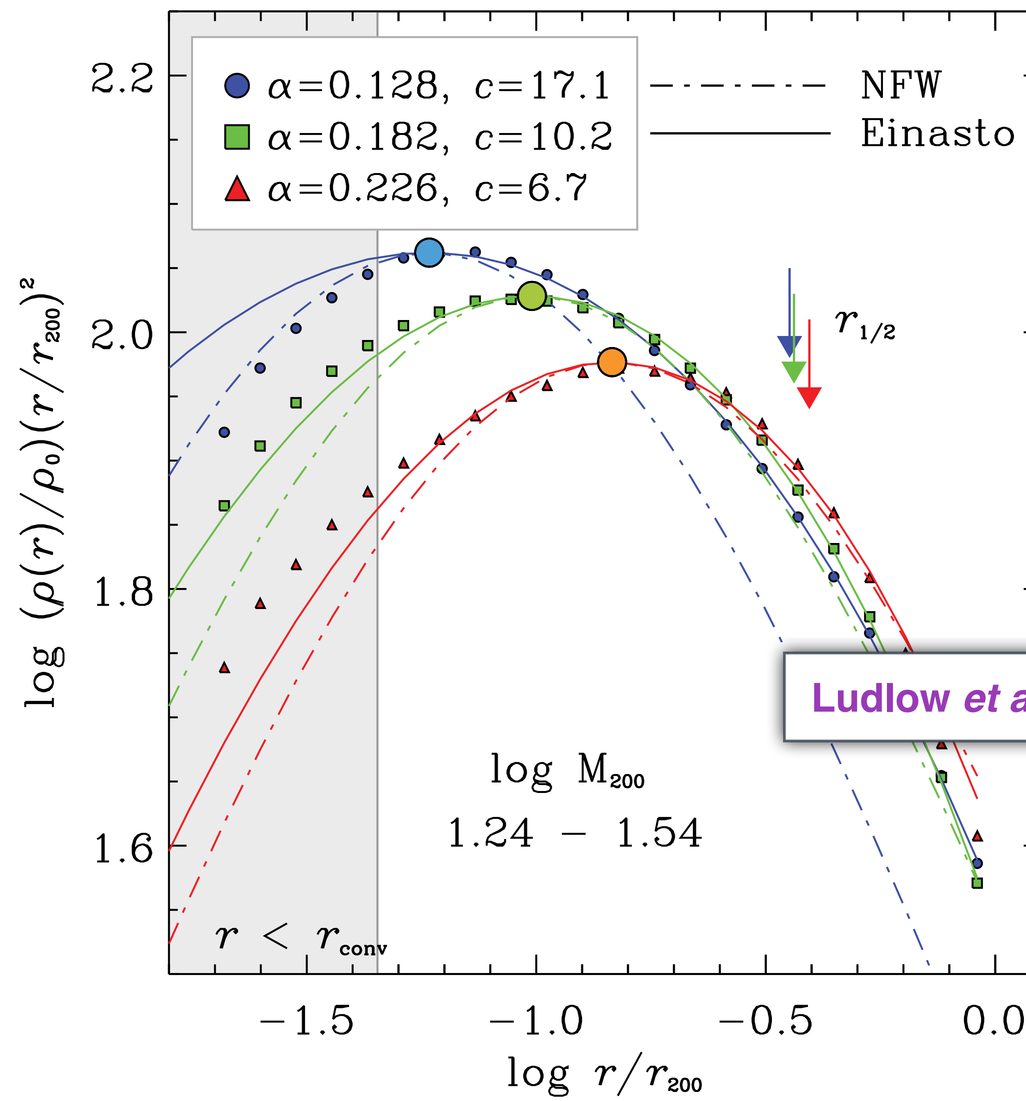
Ingredients:

1. Halos mass function
2. Halos **density profile** (NFW, Einasto, etc ...)

e.g.

$$\rho_{NFW}(r) = \frac{\rho_0}{\frac{r}{R_s}\left(1+\frac{r}{R_s}\right)^2}$$



Ludlow *et al.* (2013)

The Halo Model approach

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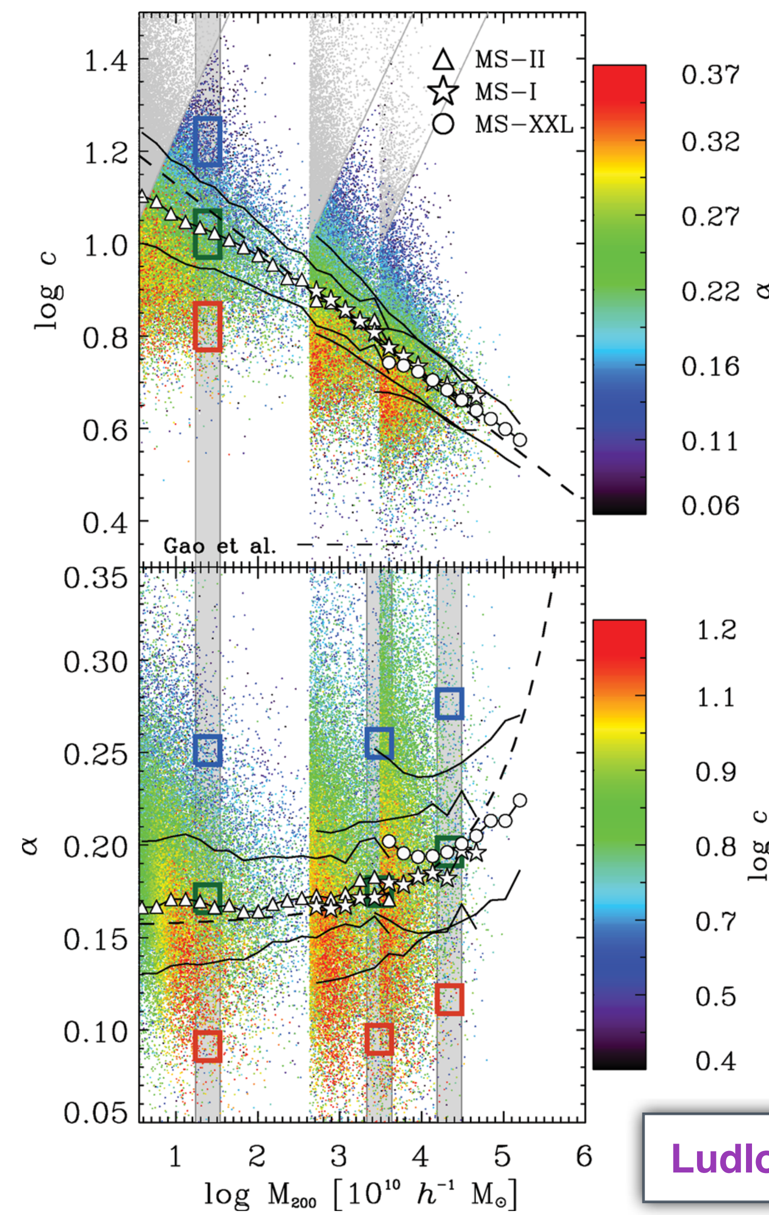
Ingredients:
1. Halos mass function
2. Halos density profile (NFW, Einasto, etc ...)
3. Halos **concentration**

e.g.

$$c_v(M,z) = \frac{R_v}{R_s}$$



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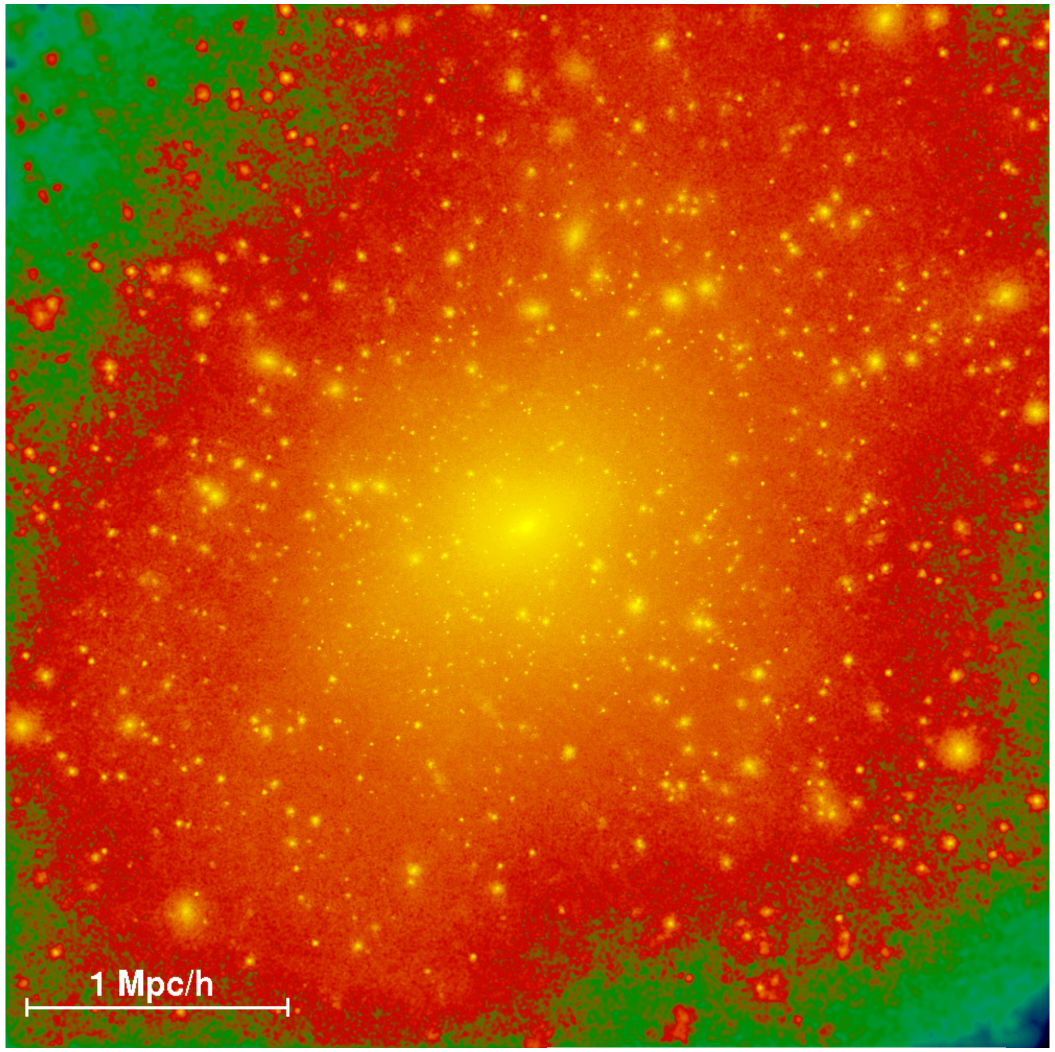
Ingredients:
1. Halos mass function
2. Halos density profile (NFW, Einasto, etc ...)
3. Halos concentration
+ all of the above for **subhalos**



Dark matter in the S3 cluster.
Springel, White & Tormen (1999)

Max-Planck-Institut
für Astrophysik

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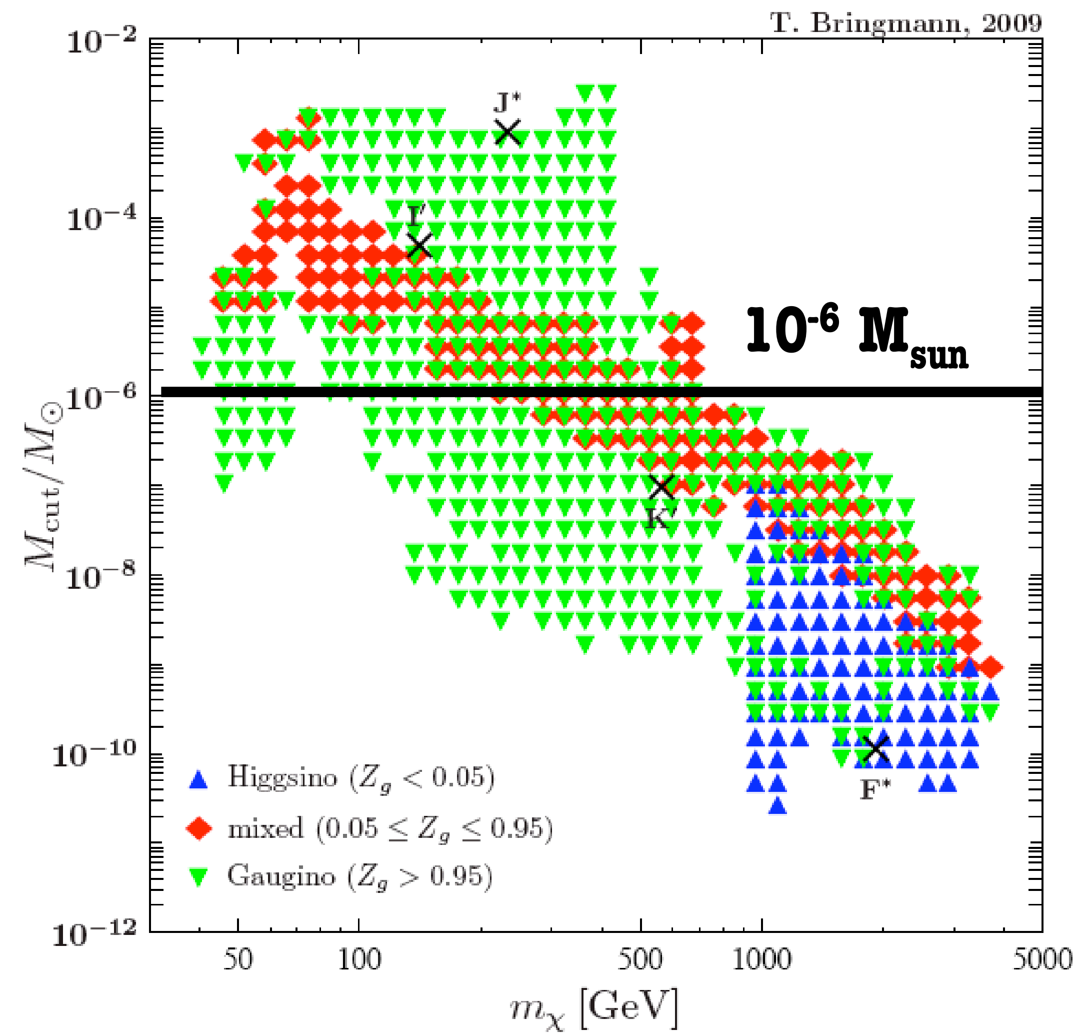
+ all of the above for subhalos

Typical M_{min} for a WIMP = 10^{-6} M_{sun}



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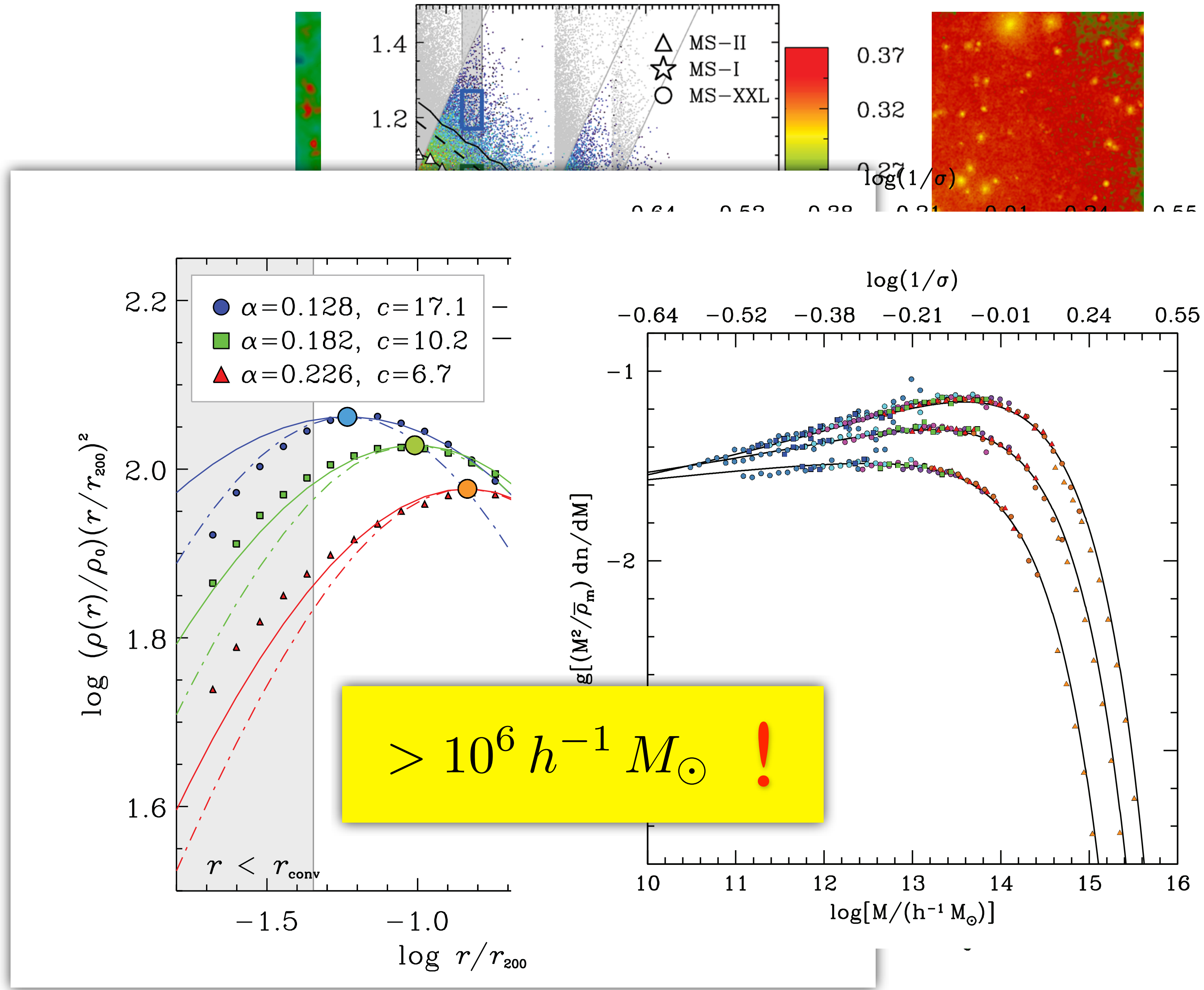

$> 10^6\,h^{-1}\,M_\odot$!

The Halo Model approach

$$\rho(z,\hat{\Omega}) = \bar{\rho}(z)\,\Delta(z,\hat{\Omega})$$

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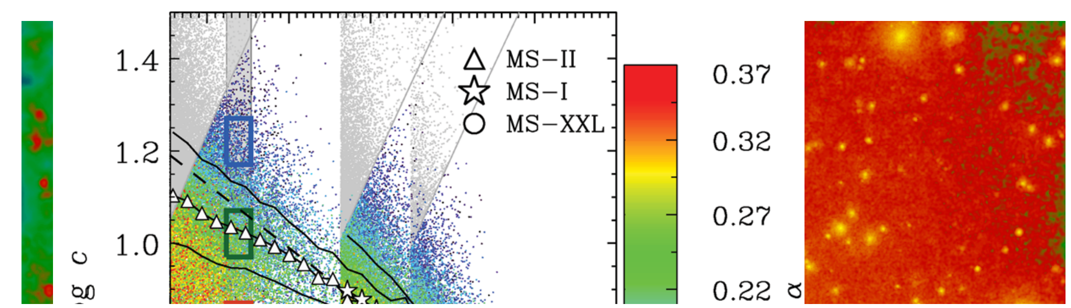
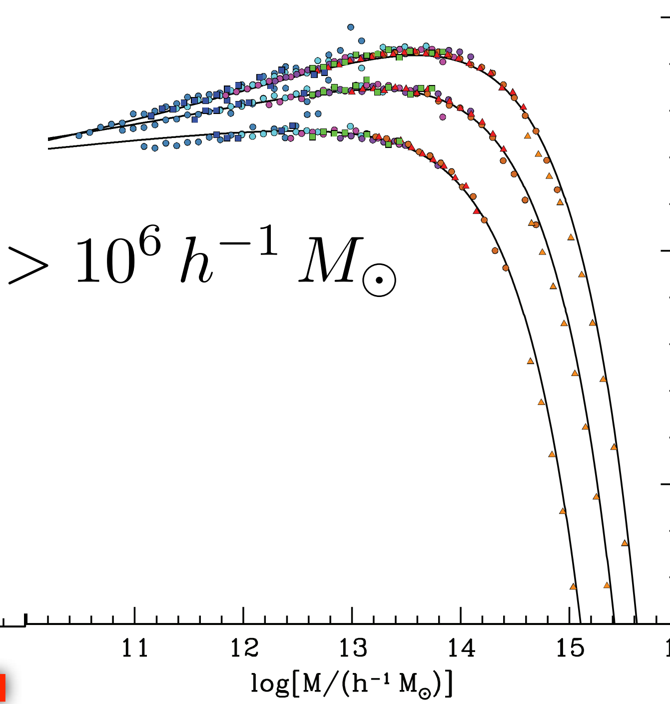


an extrapolation of more than 10 orders of magnitude!



$> 10^6 \, h^{-1} \, M_\odot$

$10^{-9}, 10^{-6} \, h^{-1} \, M_\odot$?

A *Power Spectrum* approach

$$\rho(z,\hat{\Omega}) = \bar{\rho}(z)\,\Delta(z,\hat{\Omega}) = \bar{\rho}(z)\,\left[1+\delta(z,\hat{\Omega})\right]$$

$$\longrightarrow \boxed{\zeta(z) = \langle \delta^2(z,\hat{\Omega}) \rangle}$$

Enter: the dark matter power spectrum

$$\langle \delta(\vec{x})\delta(\vec{y}) \rangle \equiv \xi(|\vec{x}-\vec{y}|) = \frac{1}{(2\pi)^3}\int e^{ik|\vec{x}-\vec{y}|} P(k)$$

$$\langle \delta^2(\vec{x}) \rangle \equiv \xi(0) = \frac{1}{2\pi^2}\int dk\, k^2\, P(k)$$

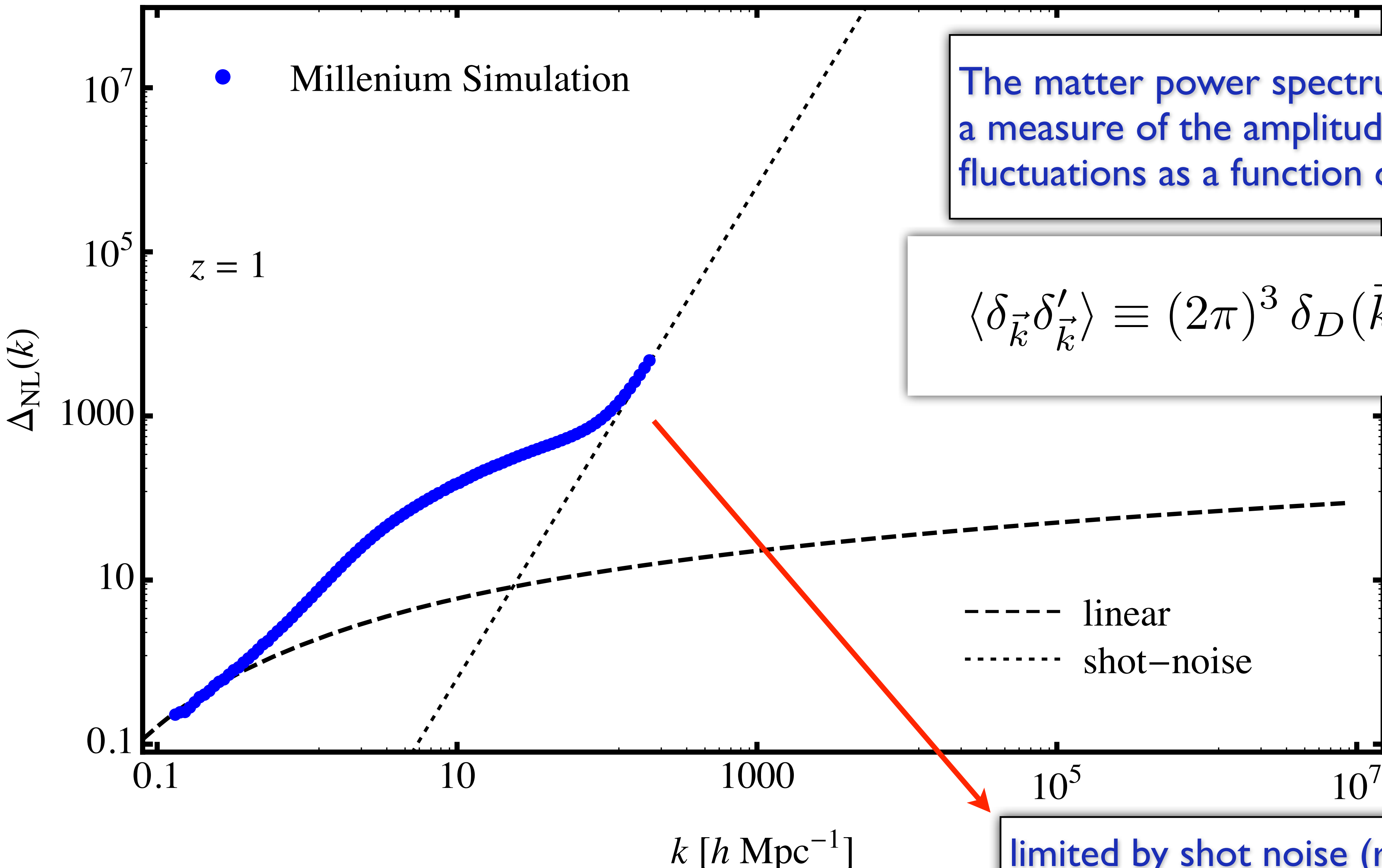
$$\zeta(z) = \langle \delta^2(z,\hat{\Omega}) \rangle = \int_0^{k_{max}} \frac{dk}{k}\, \frac{k^3\, P_{NL}(k)}{2\pi^2}$$

all-in-one function!

The nonlinear matter Power Spectrum

$$\zeta(z) = \langle \delta^2(z, \hat{\Omega}) \rangle = \int_0^{k_{max}} \frac{dk}{k} \Delta_{NL}(k)$$

$$\Delta_{NL}(k) \equiv \frac{k^3 \, P_{NL}(k)}{2\pi^2}$$



The matter power spectrum:
a measure of the amplitude of matter fluctuations as a function of scale.

$$\langle \delta_{\vec{k}} \delta'_{\vec{k}} \rangle \equiv (2\pi)^3 \, \delta_D(\vec{k} + \vec{k}') \, P(k)$$

limited by shot noise (resolution) !

The nonlinear matter Power Spectrum

$$\zeta(z) = \langle \delta^2(z, \hat{\Omega}) \rangle = \int_0^{k_{max}} \frac{dk}{k} \Delta_{NL}(k)$$

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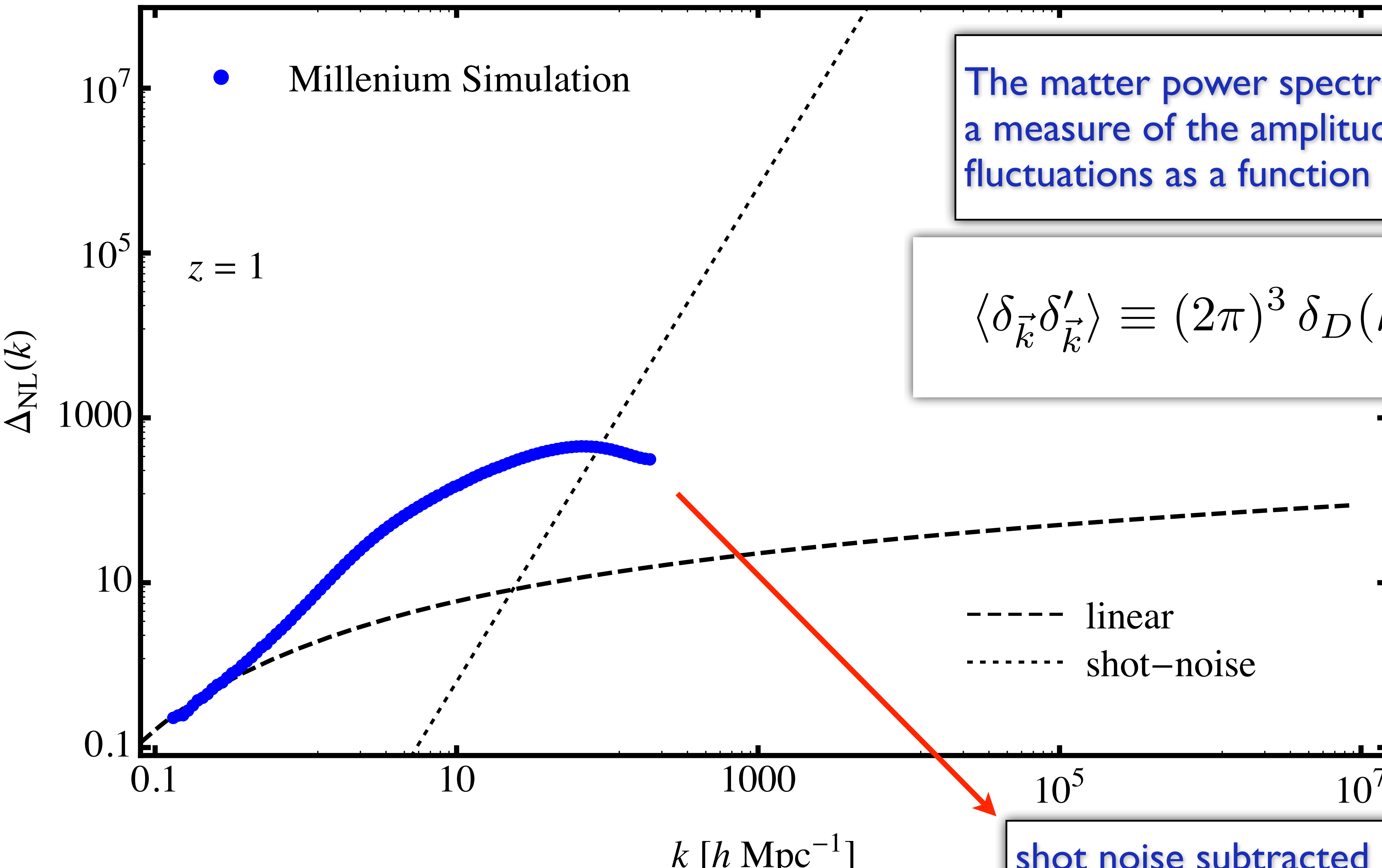

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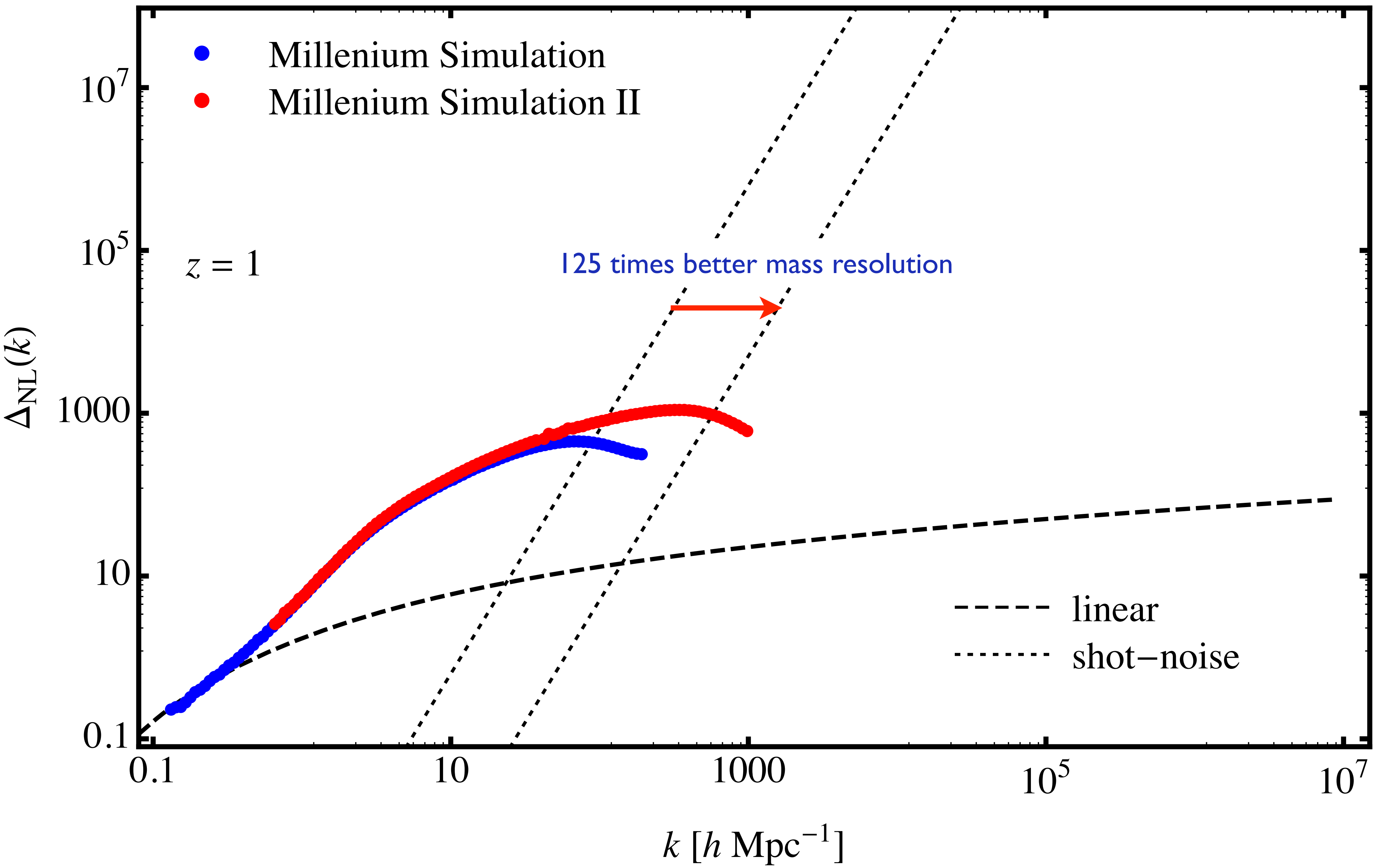
$$\langle \delta_{\vec{k}} \delta'_{\vec{k}} \rangle \equiv (2\pi)^3 \, \delta_D(\vec{k} + \vec{k}') \, P(k)$$

shot noise subtracted

The nonlinear matter Power Spectrum

$$\zeta(z) = \langle \delta^2(z, \hat{\Omega}) \rangle = \int_0^{k_{max}} \frac{dk}{k} \Delta_{NL}(k)$$

$$\Delta_{NL}(k) \equiv \frac{k^3\, P_{NL}(k)}{2\pi^2}$$



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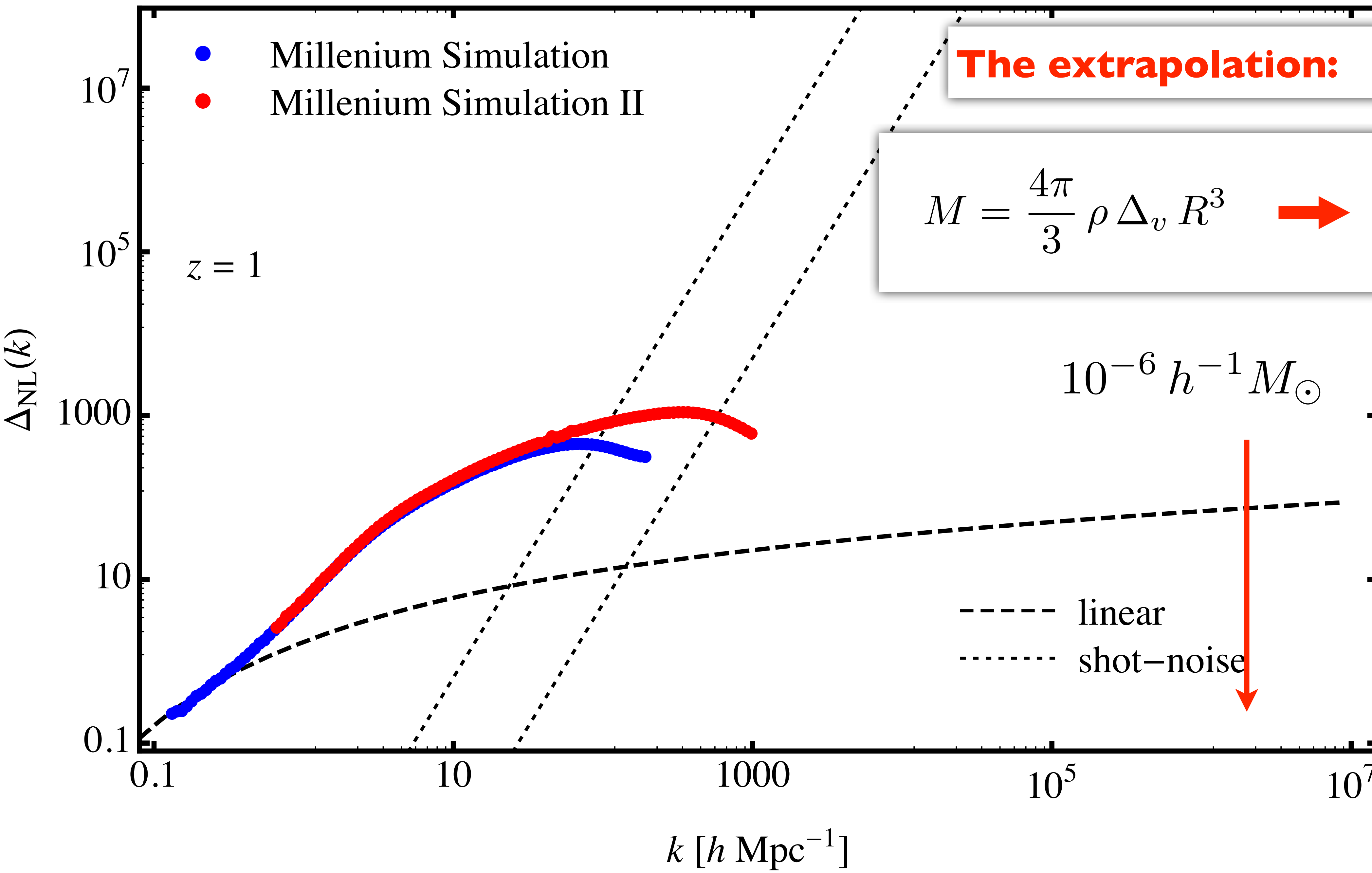


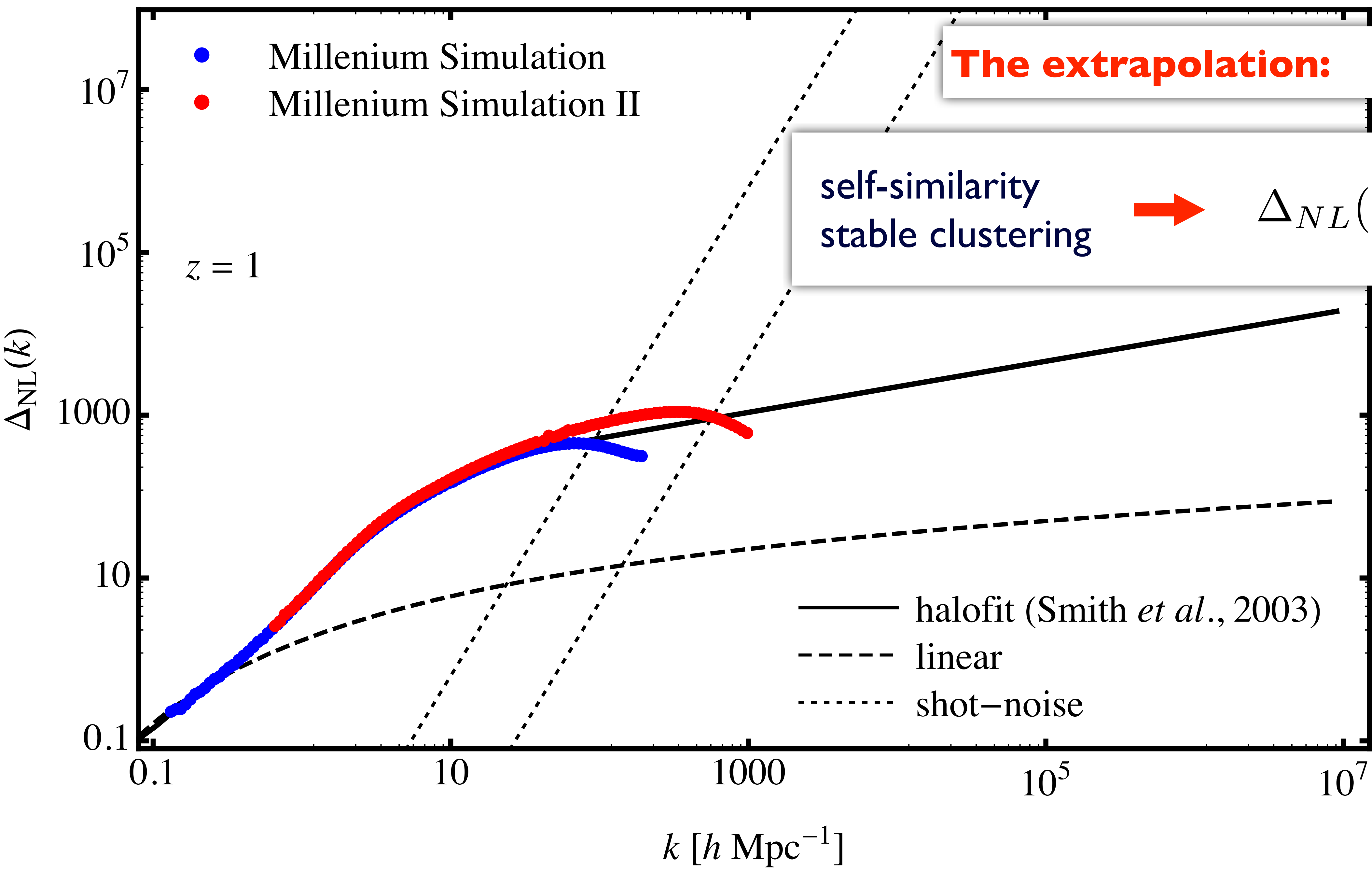
The extrapolation:

$$M = \frac{4\pi}{3}\, \rho\, \Delta_v\, R^3 \;\Rightarrow\; k_{max} \sim M_{min}^{-1/3}$$

The nonlinear matter Power Spectrum

$$\zeta(z) = \langle \delta^2(z, \hat{\Omega}) \rangle = \int_0^{k_{max}} \frac{dk}{k} \Delta_{NL}(k)$$

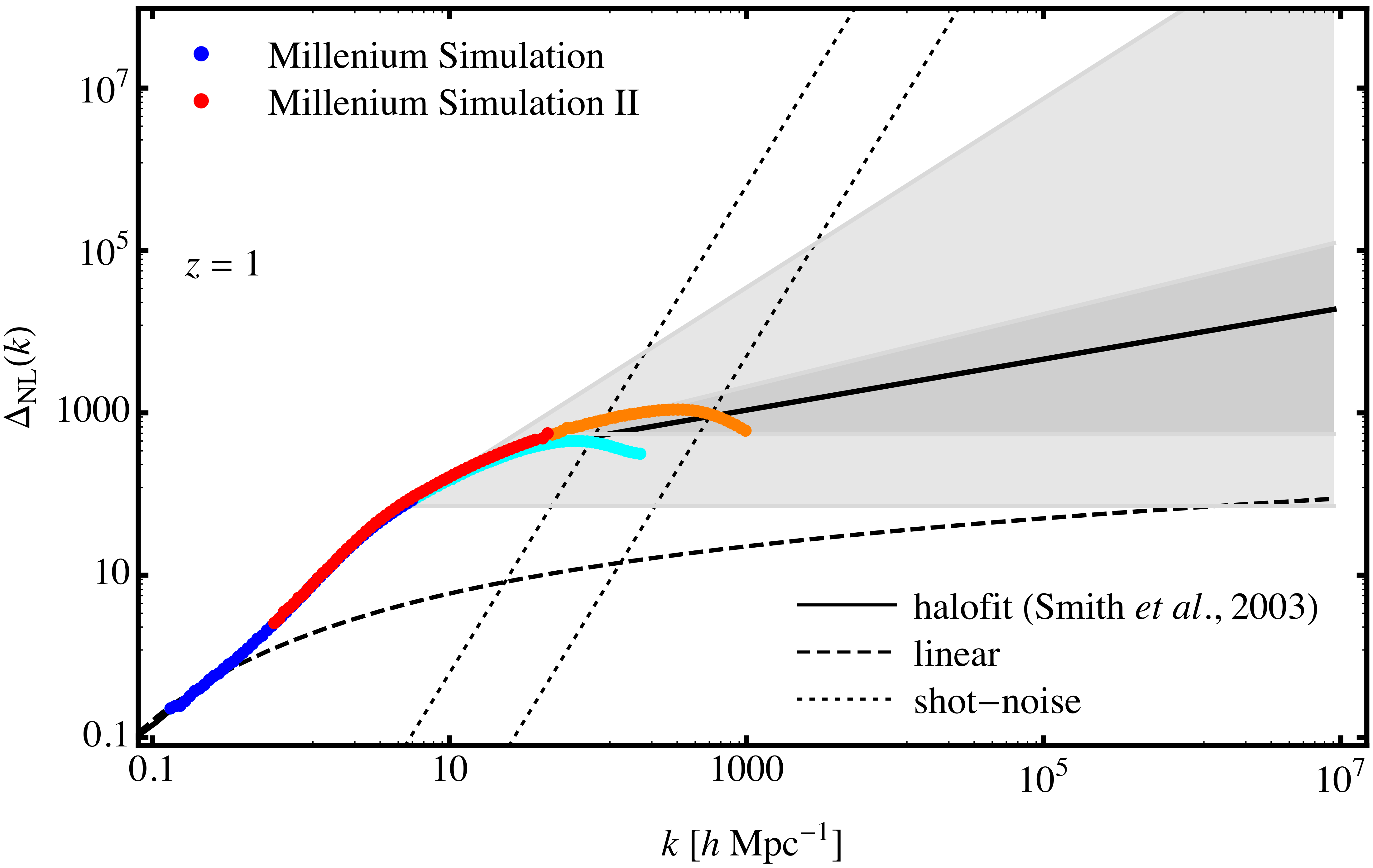
$$\Delta_{NL}(k) \equiv \frac{k^3 \, P_{NL}(k)}{2\pi^2}$$



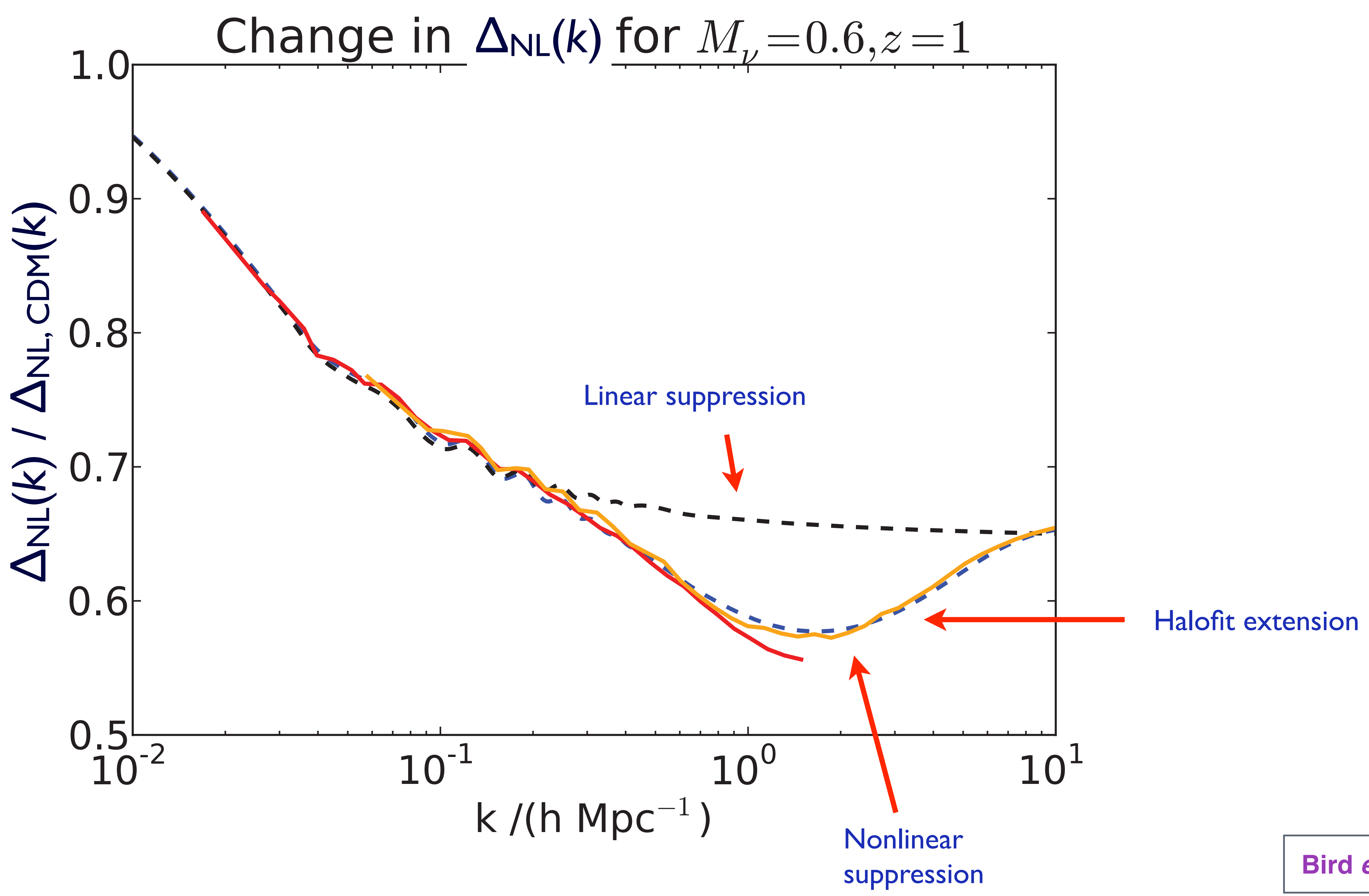
The extrapolation:

self-similarity
stable clustering → $\Delta_{NL}(k) = \mathcal{F}[\Delta_L(k_L)]$

Estimating uncertainties ...

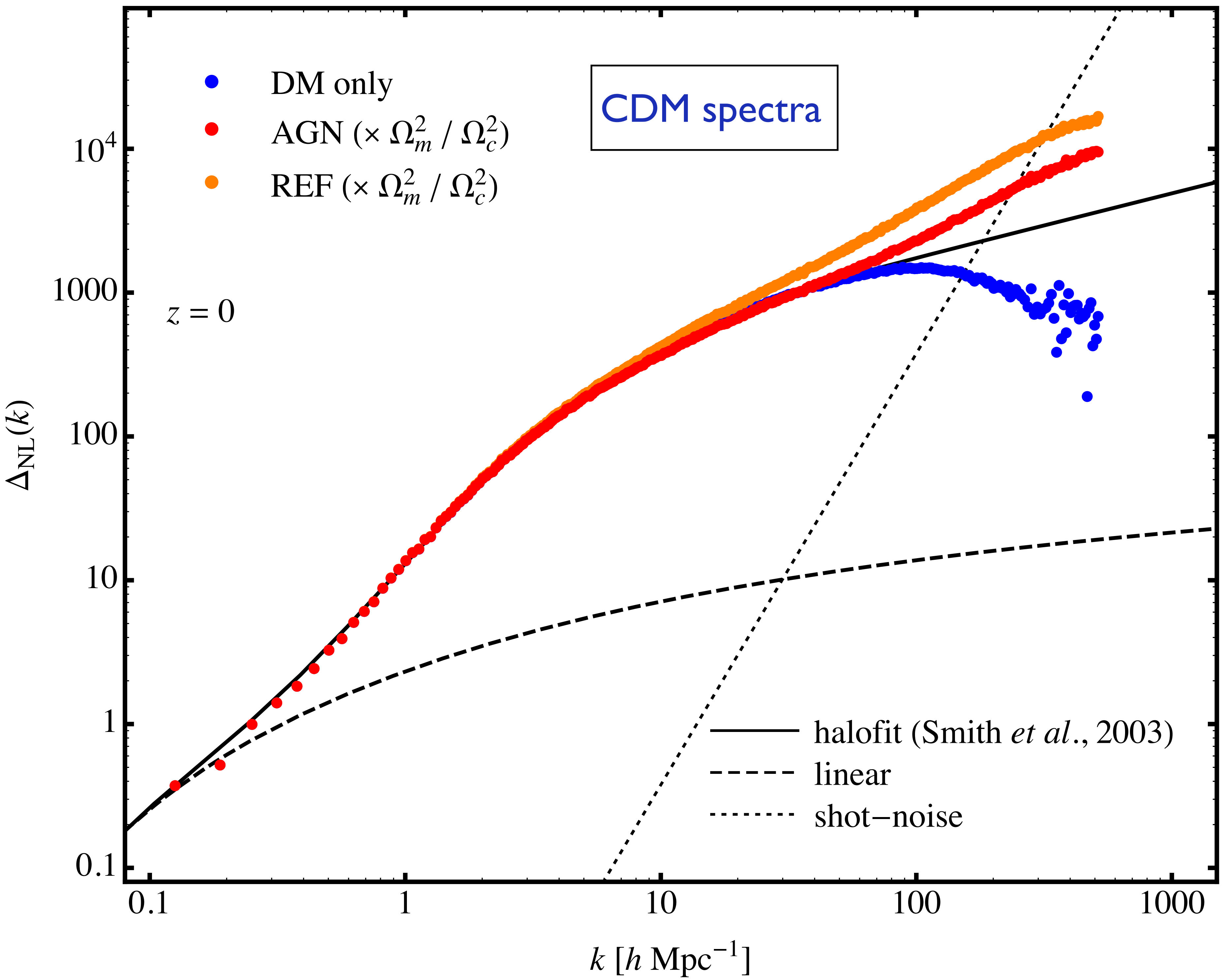


Other uncertainties: neutrinos



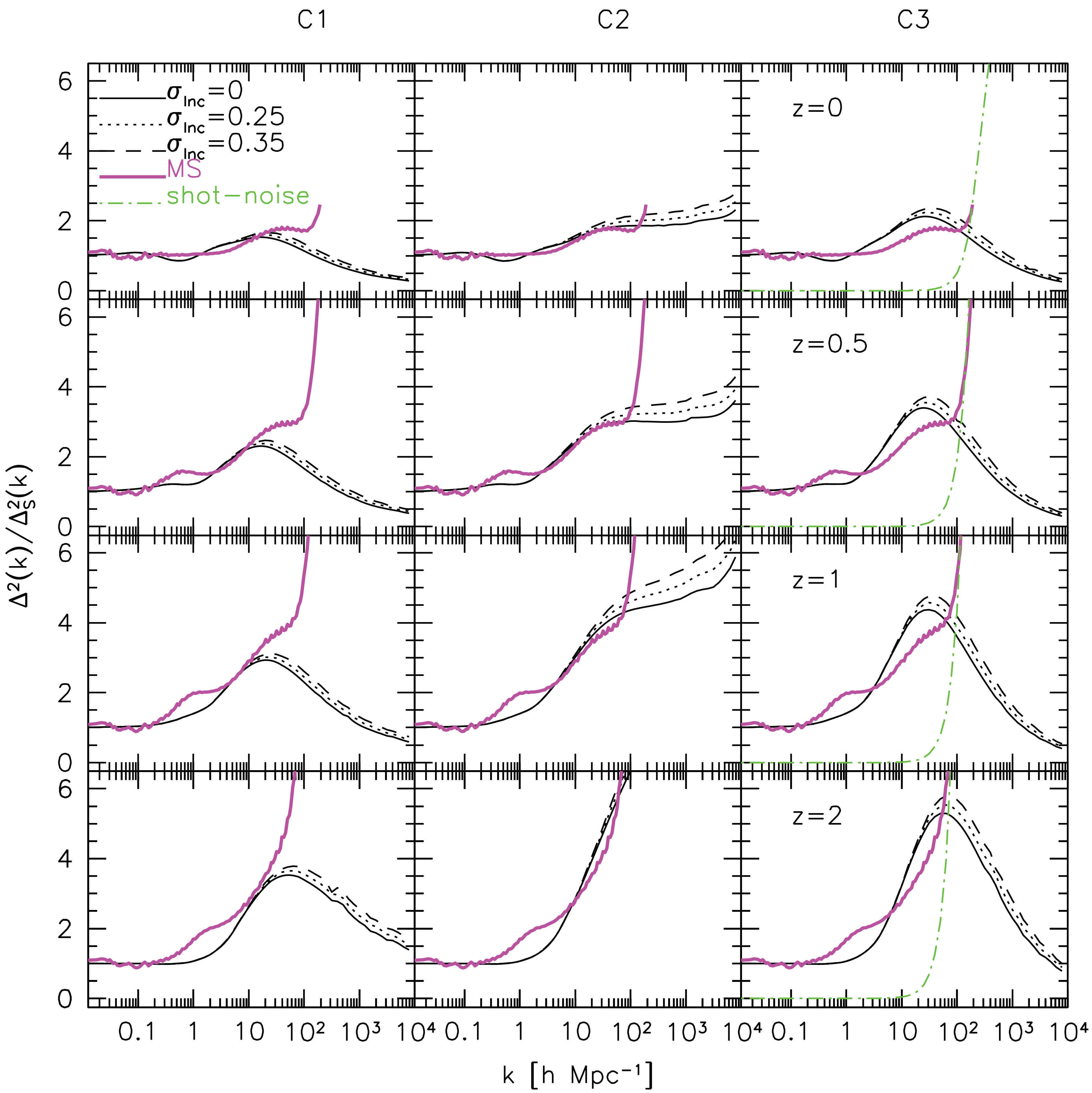
Bird *et al.* (2012)

Other uncertainties: baryons



data from van Daalen *et al.* (2011)

The nonlinear Power Spectrum *from* the Halo Model



Giocoli *et al.* (2010)

Conclusion

Halo Model:

$$\zeta(z) = \frac{1}{\Omega_m \rho_c} \int_{M_{min}} dM \frac{dn}{dM} M \frac{\Delta_{vir}(z)}{3} \langle F \rangle \qquad F = c_v^3(M,z) \frac{\int_0^{c_v} dx x^2 \kappa^2(x)}{\left[\int_0^{c_v} dx x^2 \kappa(x)\right]^2}$$

+ subhalos properties (x2)

or

Power Spectrum:

$$\zeta(z) = \langle \delta^2(z, \hat{\Omega}) \rangle = \int_0^{k_{max}} \frac{dk}{k} \frac{k^3 P_{NL}(k)}{2\pi^2}$$

The DM extragalactic annihilation flux can be computed in the Halo Model from 3 or more quantities determined from simulations
or
directly from the Power Spectrum, with minimal assumptions