Weak lensing signal from halo and subhalo population

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Collaborators

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Outline

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1. Introduction
2. Halo Model: *an extended version* with haloes and subhaloes
   - ingredients
3. Convergence Power Spectrum
4. MOKA: simulated Maps Of darK matter hAloes

Introduction

Dark Matter clusters in virialized systems called dark matter haloes.
The **Sheth & Tormen 1999** mass function well describes their number density, at a given redshift.

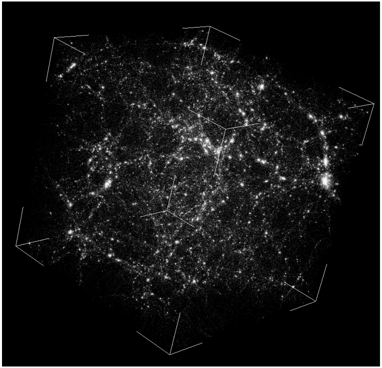
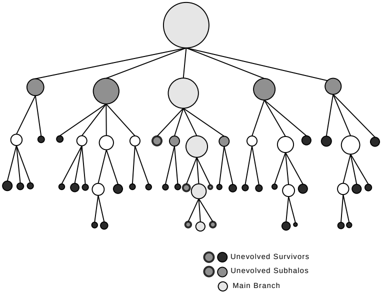


Figure: dark matter density distribution at z=0 in a cosmological N-body simulation

Introduction

They hierarchically grow, along the cosmic time, trought repeated merging events.



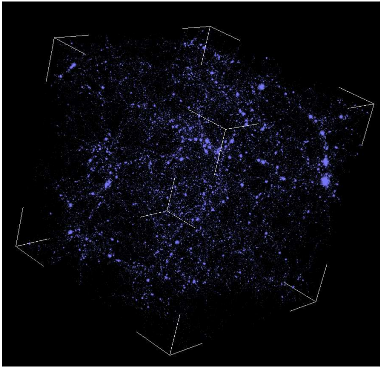


Figure: halo distribution at z=0 in a cosmological N-body simulation

Introduction

Cores of progenitor haloes may survive in the virial radius of host haloes forming the so-called substructure population.

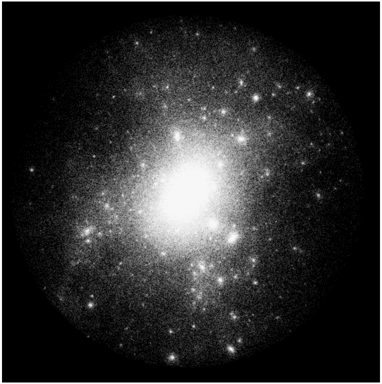


Figure: dark matter particle distribution at z=0 in the most massive halo

Introduction

Figure: clumpy component

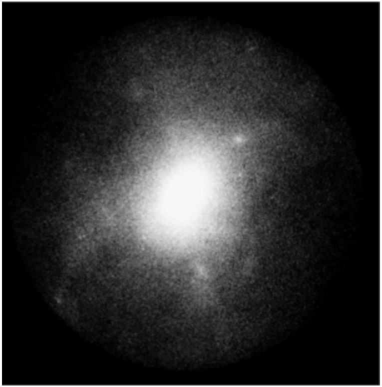


Figure: smooth component

Introduction

The subhalo mass function has a power law distribution with an exponential cut-off at large masses.
Its normalization depends on the host halo mass, redshift, concentration (**Gao et al. 2004/2010**, **De Lucia et al. 2004**, **Giocoli et al. 2008/2010a**).

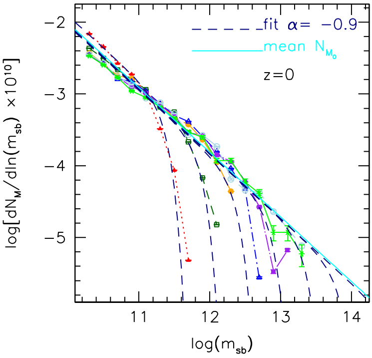


Figure: subhalo mass function at z=0 for different host halo masses

Introduction - subhalo mass function

$$\frac{dN(M,c,z)}{d\ln m} = N_{M_0} M \sqrt{1+z}\, \frac{\bar{c}(M,z)}{c} m^{\alpha} \exp\left[-\beta\left(\frac{m}{M}\right)^3\right]$$

Giocoli et al. 2010a

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- at a fixed redshift and host halo mass $\bar{c}/c$ describes the scatter in assembly history;

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- at a fixed concentration and host halo mass $\sqrt{1+z}$ describes the redshift evolution;

Giocoli et al. 2010a

Halo Model

Halo Model

1 The Halo Model for Power Spectrum assumes all the matter in form of isolated haloes of a well defined mass M and density profile $\rho(r, M)$ (**Seljak 2000, Cooray & Sheth 2002**):

$$\rho(r, M) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left(1 + \frac{r}{r_s}\right)^2}, \qquad c = \frac{R}{r_s}$$

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   - 2-Halo term:

$$P_{2H}(k,z) = P_{\rm lin}(k)\left[\int \frac{M}{\bar{\rho}} n(M,z)\, b(M,z) u(k|c(M))\, b(M,z)\, dM\right]^2$$

extended Halo Model

The *extended* Halo Model for Power Spectrum assumes all the matter in form of haloes which are made of a smooth and a clumpy component. Subhalo population is characterized by a mass function, a radial density distribution in the host and a mass density profile.

The matter Power spectrum is the sum of 7 contributions that take into account the mutual correlation, on small and large scale, between smooth and clump components (**Sheth & Jain 2003** and **Giocoli, Bartelmann et al. 2010b**).

extended Halo Model

1 Halo term - small scales

2 Halo term - large scales

extended Halo Model

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1 smooth-smooth

2 Halo term - large scales

extended Halo Model

1 Halo term - small scales

1. smooth-smooth
2. smooth-clump

2 Halo term - large scales

extended Halo Model

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3. clump-clump

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4. *self*-clump

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extended Halo Model

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2 Halo term - large scales

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6. smooth-clump
7. clump-clump

extended Halo Model

$$
\begin{aligned}
P(k,z) &= P_{1H,ss}(k,z) + P_{1H,sc}(k,z) + P_{1H,cc}(k,z) + P_{1H,self-c}(k,z) \\
&+ P_{2H,ss}(k,z) + P_{2H,sc}(k,z) + P_{2H,cc}(k,z)
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Ingredients:

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Ingredients:

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Ingredients:

1. *Halo mass function* and *bias*
2. *Halo mass density profile* and *mass concentration relation*

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Ingredients:

1. *Halo mass function* and *bias*
2. *Halo mass density profile* and *mass concentration relation*
3. *Subhalo mass function*

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2 *Halo mass density profile* and *mass concentration relation*

3 *Subhalo mass function*

4 *Subhalo density distribution*, *mass density profile* and *mass concentration relation*

6 *Log-normal scatter in the mass concentration relations*

extended Halo Model: $\Delta^2(k,z) = \frac{k^3 P(k,z)}{2\pi^2}$

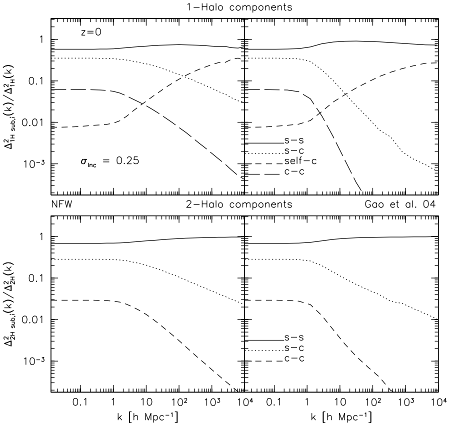


Figure: relative contributions of the *extended* Halo Model terms

extended Halo Model: $\Delta^2(k,z) = \frac{k^3 P(k,z)}{2\pi^2}$

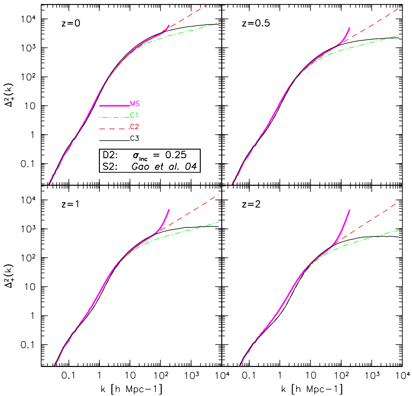
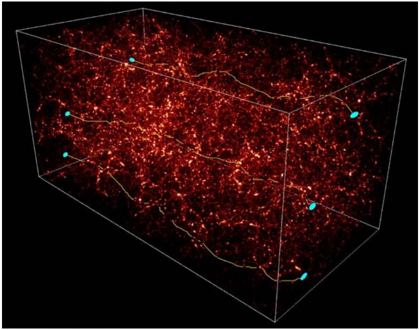
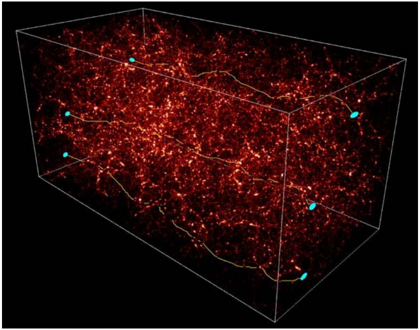


Figure: Power Spectrum reconstruction with the *extended* Halo Model, three models for the mass concentration relation are considered: C1 **Neto et al. 2007**, C2 **Seljak 2000** and C3 **Zhao et al. 2009**.

Convergence Power Spectrum



Convergence Power Spectrum



$$P_\kappa(l) = \frac{9H_0^4\Omega_o^2}{4c^4}\int_0^{w_H}\frac{\bar{W}^2(w)}{a^2(w)}P_\delta\left(\frac{l}{f_k(w)}, w\right)dw$$

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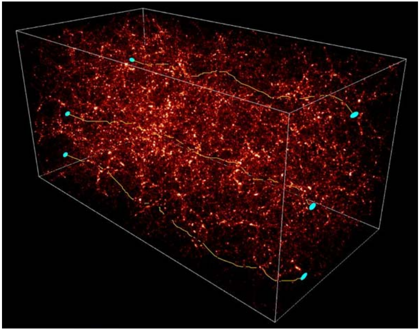

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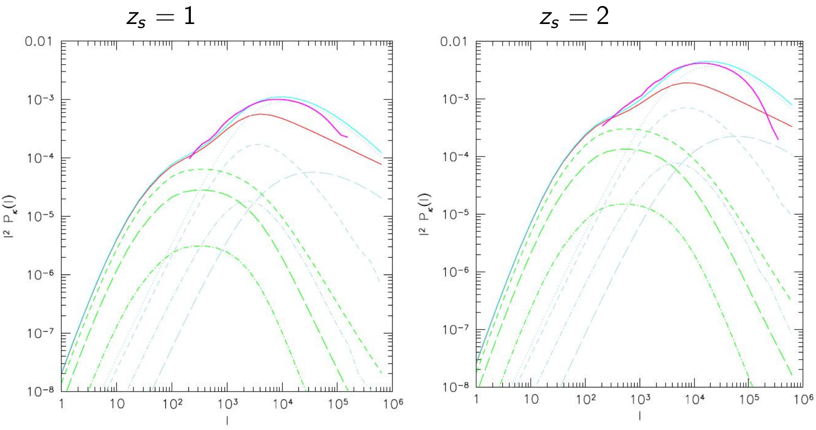
$$P_\kappa(l) = \sum^{7} P_{\kappa,i}(l)$$

Convergence Power Spectrum



Smith et al. 2003, MS (**Hilbert et al. 2009**) and *extended* Halo Model

MOKA

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Software based on the *extended* Halo Model which allows to create lensing maps of substructured dark matter haloes.

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1. lens and sources redshifts

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4. subhaloes radial density distribution

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Why?

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Why?

- Large statistical sample of haloes

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- Lensing signal dependence on halo and subhalo properties

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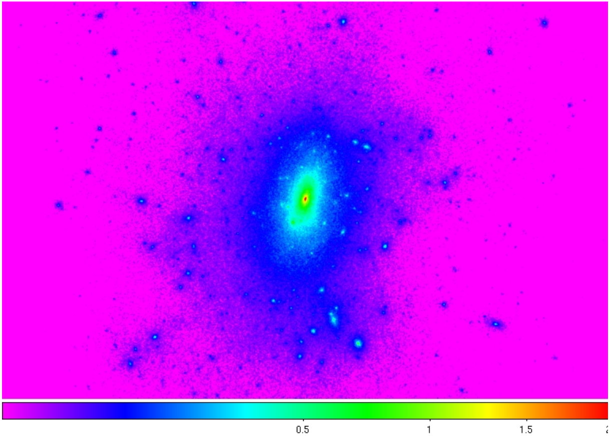
Why?

- Large statistical sample of haloes
- Lensing signal dependence on halo and subhalo properties
- Test the ingredients of the *extended* Halo Model

convergence map: halo from a cosmological simulation



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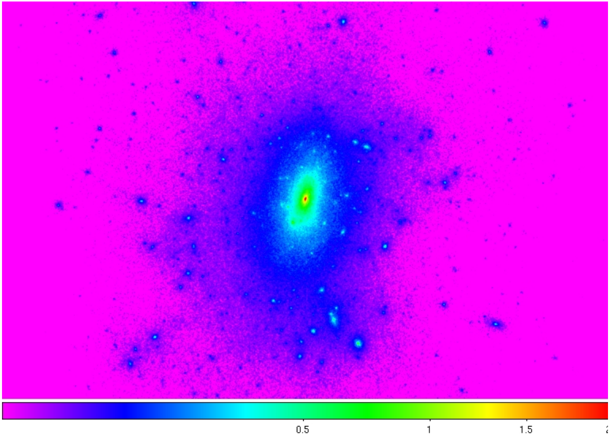
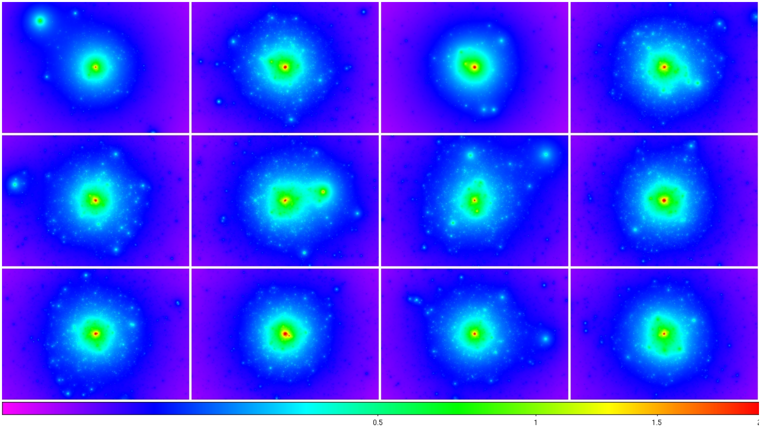


mass resolution

convergence map: 12 clusters by MOKA



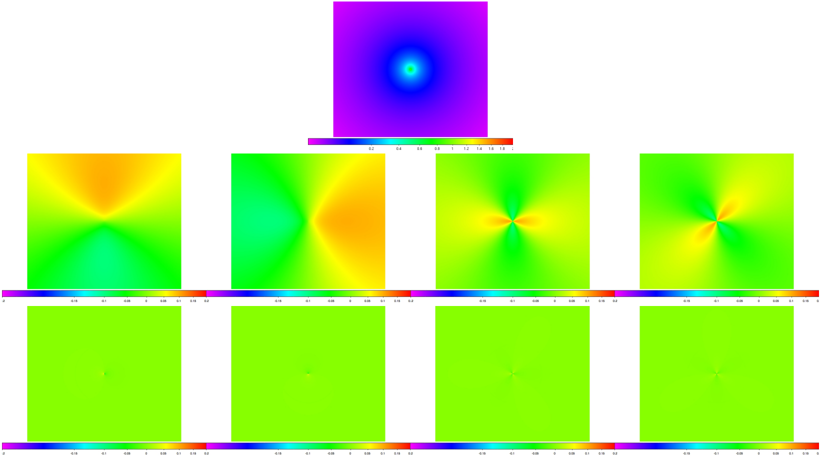
Gravitational lensing

$$\partial = \partial_x + i\partial_y$$

$$\begin{aligned}
\vec{\alpha} &= \partial\Psi \\
\kappa &= \partial^*\partial\Psi \\
\vec{\gamma} &= \frac{1}{2}\partial\partial\Psi \\
\vec{F} &= \frac{1}{2}\partial\partial^*\partial\Psi = \partial^*\vec{\gamma} \\
\vec{G} &= \frac{1}{2}\partial\partial\partial\Psi = \partial\vec{\gamma}
\end{aligned}$$

In case of a NFW matter density profile distribution we can solve these equations analytically (see **Bartelmann 1996**).

MOKA: halo without substructures



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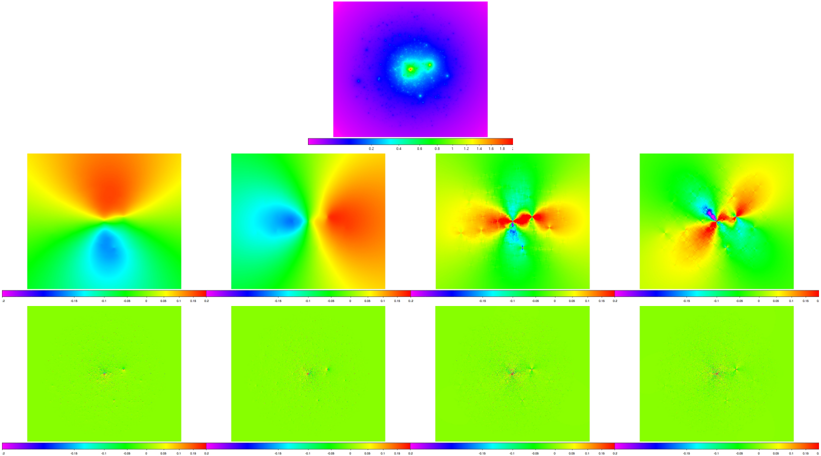

Ellipticity: MOKA

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haloes are not spherical

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- haloes are not spherical
- scale of the substructure ellipticity is small with respect to that of the host haloes

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- re-map the mass distribution in the smooth halo component and the subhalo distribution (**Li et al. 2008**).

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re-map the mass distribution in the smooth halo component and the subhalo distribution (**Li et al. 2008**).

consider a triaxial model where $\rho_{TRI}(R)$ where R specify the ellipsoidal surface:

$$R^2 = \left(\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} \right) c^2$$

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re-map the mass distribution in the smooth halo component and the subhalo distribution (**Li et al. 2008**).

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satellite distribution $n_{TRI}(R) = n_{sat}(r)$

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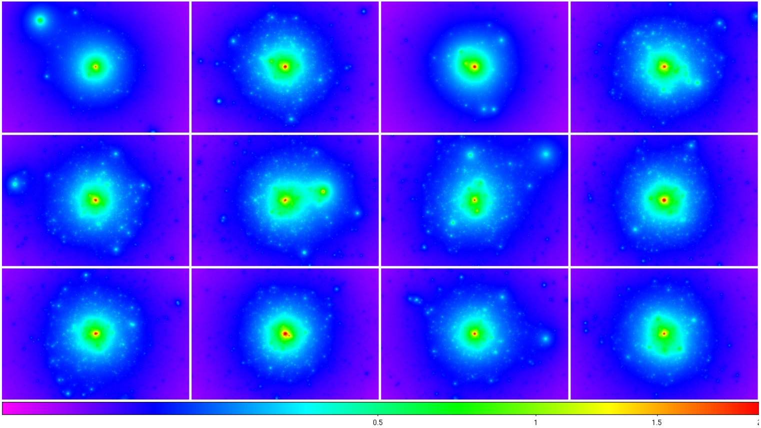
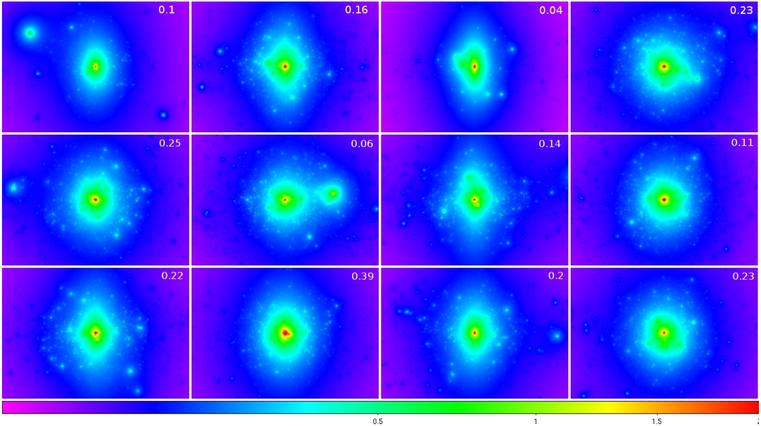
a/c and b/c are taken from the distributions $p(a/c)$ and $p(b/c|a/c)$ by **Jing and Suto 2002** to estimate the ellipticity.

convergence map: 12 clusters by MOKA



convergence map: 12 clusters by MOKA with ellipticity



MOKA: Flexion Power Spectrum from Galaxy Clusters

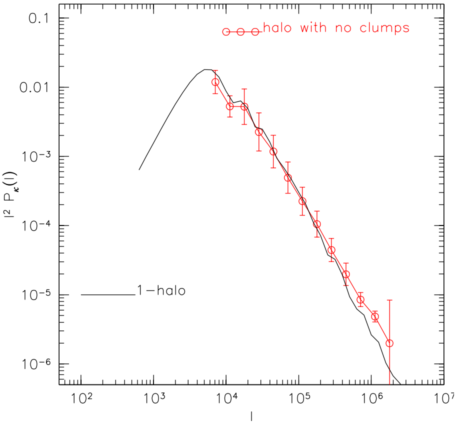


Figure: Haloes without substructures

MOKA: Flexion Power Spectrum from Galaxy Clusters

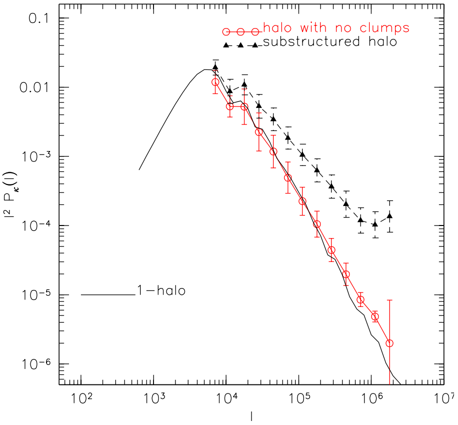
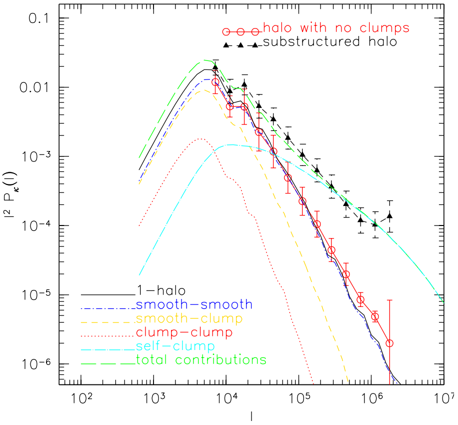


Figure: Haloes with and without substructures

MOKA: Flexion Power Spectrum from Galaxy Clusters



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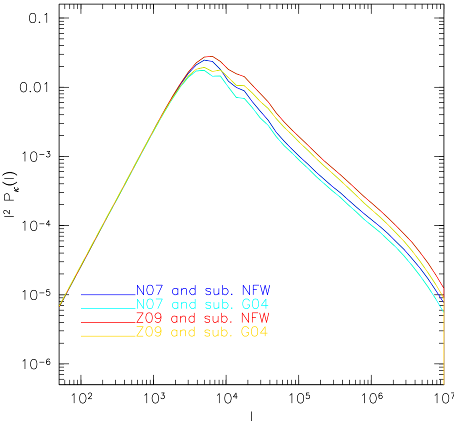

Figure: Dependence on structural parameters

Summary

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- *extended* Halo Model

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- decomposed the convergence power spectrum in different contributions considering the presence of substructures in host haloes

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- *extended* Halo Model
- decomposed the convergence power spectrum in different contributions considering the presence of substructures in host haloes
- `MOKA` maps of substructured haloes and subhalo lensing signal