Halo abundances and shear in void models.

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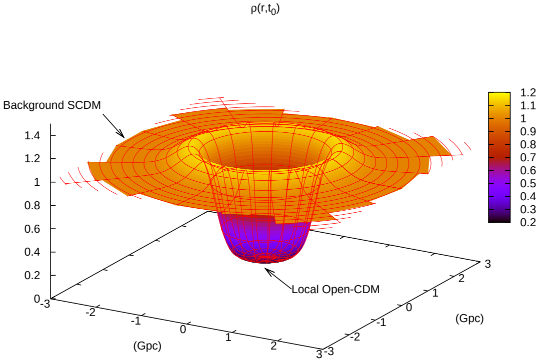
Based on the work:
astro-ph:1204.3532
In collaboration with:
J. García-Bellido, A. Knebe, T. Haugbølle

August 17th 2012

Void models


ρ(r,t0)
Background SCDM
Local Open-CDM
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-3
-2
-1
0
1
2
3
(Gpc)
(Gpc)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2

Cosmological models.

Friedmann-Robertson-Walker (FRW)

$$ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{1-k\,r^2} + r^2 d\Omega^2\right], \quad a = \frac{1}{1+z}$$

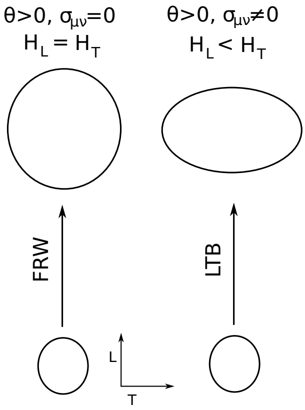
$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = H_0^2\left[\Omega_M\, a^{-3} + \Omega_k\, a^{-2} + \Omega_\Lambda\, a^{-3(1+w)}\right]$$

Lemaître-Tolman-Bondi (LTB)

$$ds^2 = -dt^2 + \frac{(A'(t,r))^2}{1-k(r)}dr^2 + A^2(t,r)d\Omega^2, \quad H_T \equiv \frac{\dot{A}}{A}, \quad H_L \equiv \frac{\dot{A}'}{A'}$$

$$H_T^2(t,r) = H_0^2(r)\left[\Omega_M(r)\left(\frac{A_0(r)}{A(t,r)}\right)^3 + (1-\Omega_M(r))\left(\frac{A_0(r)}{A(t,r)}\right)^2\right]$$

Shear



- Comoving geodesics have non-vanishing shear.
- Expansion $+$ deformation
- Crucial for perturbations

Perturbation theory.

Perturbation theory in LTB models is complicated[1].

- No background homogeneity $\Rightarrow$ No $SO(3)$ splitting.
- Scalar and tensor modes coupled through the background shear.

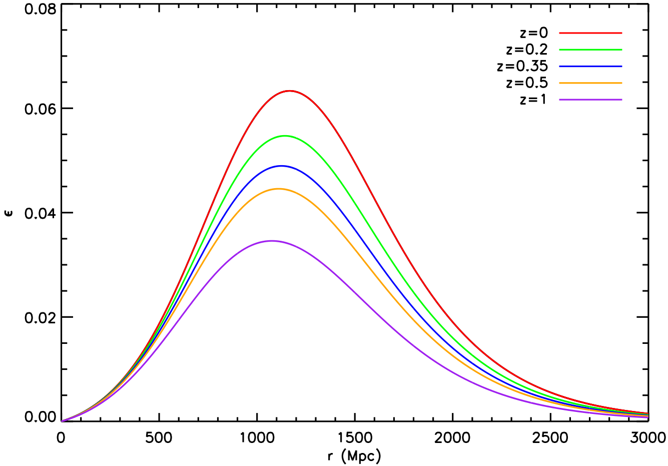
$$\ddot{\Psi} + 4\,H_T\,\dot{\Psi} - \frac{2\,k(r)}{A^2}\Psi \propto \sigma^{\mu\nu}\tau^{\rm pert}_{\mu\nu} + (...)$$

- Background shear can be characterised by a normalized shear-to-expansion ratio:

$$\epsilon \equiv \sqrt{\frac{2}{3}\frac{\sigma_{\mu\nu}\sigma^{\mu\nu}}{\theta^2}} = \frac{H_T - H_L}{2\,H_T + H_L}$$

[1] arXiv:0903.5040,1206.1602 and Sean's talk!

Perturbation theory



Perturbation theory.

But...

- 0-shear approximation: FRW perturbation theory at each r.

$$\delta_0(t,r) \propto D(\Omega_M(r), A(t,r)/A_0(r))$$

- Small shear effects could be encoded in a first-order correction

$$\delta_\alpha(t,r) \propto D(\Omega_M(r), A(t,r)/A_0(r))\left[1+\alpha\,\epsilon(t,r)\right]$$

Where, in principle

$$\alpha = \alpha(t, r, \Omega, ...)$$

Mass function

- $n(M)\,dM$: number density of halos of mass $M \in (M, M + dM)$.
- Press & Schechter theory: abundance of non-linear structures is determined by spherical collapse $+$ linear perturbation theory $+$ gaussian δ.
- Bottomline: the mass function is a **universal** function of the variance of the linear density contrast: $\sigma(M, z)$.

$$n(M, z) = \frac{\rho_M}{M} g(\sigma) \left| \frac{d \ln \sigma}{dM} \right|,$$

- Different parametrisations of the mass function can be found in the literature.

Mass function

Recipe for the mass function in LTB growing-mode voids:

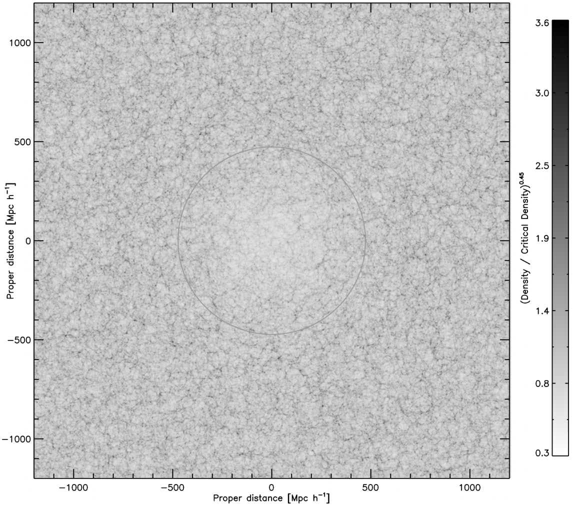
1. Calculate $\sigma(M)$ outside the void.
2. Rescale it by a factor

$$g(t,r)=\frac{\delta(t,r)}{\delta(t,r=\infty)}$$

3. Use your favourite mass function parametrisation with this rescaled variance.
4. We will show results in terms of

$$n(>M,<r,z)\equiv\frac{3}{4\pi\,r^3}\int_0^r r'^2dr'\int_M^\infty dM'\,n(M',r',z).$$

Method.



Alonso et al. arXiv:1010.3453

Method

In N-body simulations of FRW universes perturbations are generated by displacing the particles from their ideal comoving positions before the first timestep by using the Zel'Dovich approximation

$$\mathbf{q} = \mathbf{q}_i - i \sum_{\mathbf{k}} \frac{\delta_{\mathbf{k}}(t)}{k^2} \mathbf{k} e^{i\mathbf{k}\cdot\mathbf{q}}.$$

In our case we must also account for the displacement due to the background void. To do this:

1. Calculate standard transfer function for perturbations in the flat EdS background and use existing software to calculate the initial gravitational potential $\phi^i_{\mathbf{k}}$.
2. Add to this the potential due to the void from the exact LTB solution $\phi^v_{\mathbf{k}}$.
3. Use existing software to calculate particle displacements with the total potential.

Simulations performed.

Name	z_{start}	Ω_{in}	$\Delta r/r_0$	#particles	Comments
$\mathcal{H}$	24	0.25	0.3	960^3	High res sim
$\mathcal{V}$	49	0.25	0.3	512^3	Void alone
$\mathcal{S}24$	24	0.25	0.3	512^3	Void + matter
$\mathcal{S}49$	49	0.25	0.3	512^3	Void + matter
$\mathcal{S}99$	99	0.25	0.3	512^3	Void + matter
$\mathcal{S}\Omega125$	49	0.125	0.3	512^3	Void + matter
$\mathcal{S}\Omega063$	49	0.0625	0.3	512^3	Void + matter
$\mathcal{S}\Omega021$	199	0.0208	0.3	512^3	Void + matter
$\mathcal{S}\Delta01$	49	0.125	0.1	512^3	Void + matter
$\mathcal{S}\Delta05$	49	0.125	0.5	512^3	Void + matter
$\mathcal{L}$	49	0.25	0.3	768^3	L=3600 Mpc h^{-1}

In all cases $r_0 = 1100\,\mathrm{Mpc}$ and $H_0 = 64\,\mathrm{km\,s^{-1}},\ \mathrm{Mpc}^{-1}$.
Mass resolution is $m_p = 4.3 \times 10^{12}\, M_\odot\, h^{-1}$ $(\mathcal{H})$

Background evolution.

We checked that the simulations reproduce the background evolution correctly by comparing data and theoretical predictions for: density profile and expansion rates.

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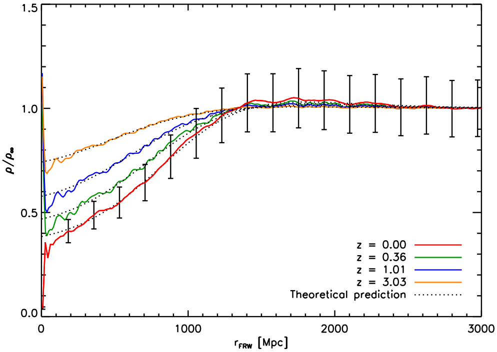

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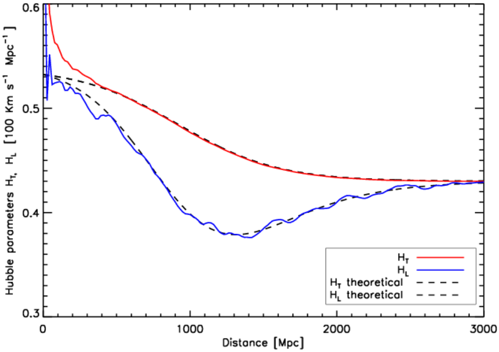


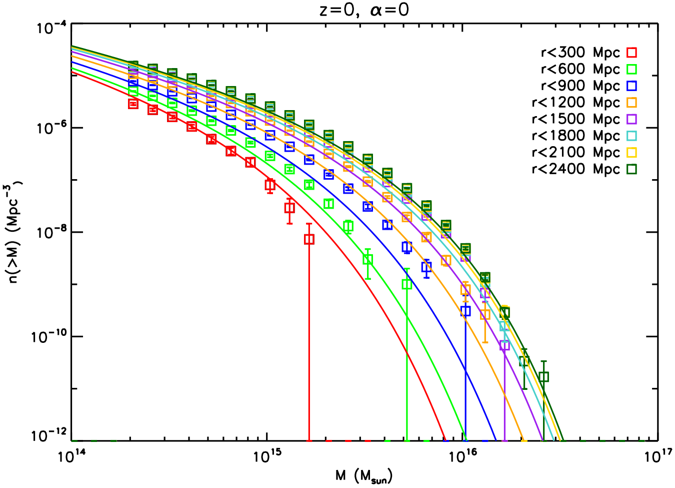
The halo catalog

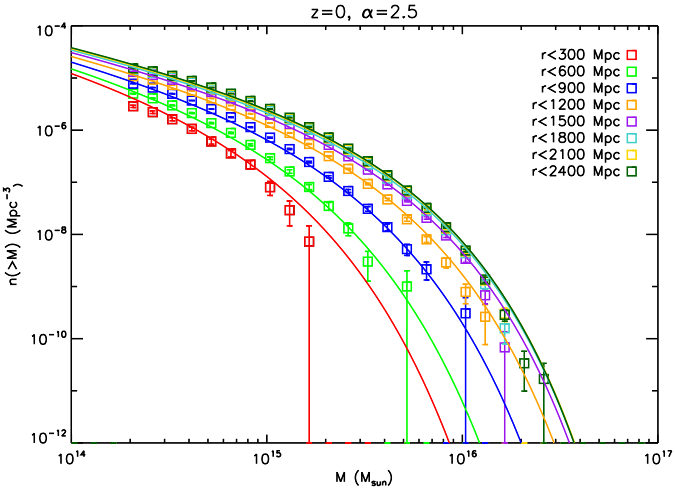
The halos were extracted using AHF (Knollmann & Knebe, 2009, ApJS, 182, 608).

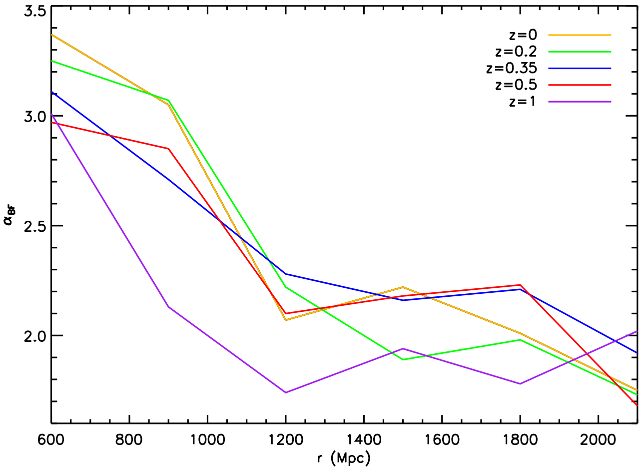
1. Create adaptively smoothed density field from the particle content.
2. Locate possible halos as local overdensities.
3. Extract gravitationally bound particles by iteratively solving Poisson's equation.
4. Determine halo extent and mass through

$$M(r_{\rm vir}) = \frac{4\pi}{3} r_{\rm vir}^3 \,\rho_c\, \Delta$$

(Δ is a fudge factor. We use $\Delta = 200$).


z=0, α=0
r<300 Mpc
r<600 Mpc
r<900 Mpc
r<1200 Mpc
r<1500 Mpc
r<1800 Mpc
r<2100 Mpc
r<2400 Mpc
n(>M) (Mpc^{-3})
M (M_{sun})
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{14}
10^{15}
10^{16}
10^{17}


z=0, α=2.5
r<300 Mpc
r<600 Mpc
r<900 Mpc
r<1200 Mpc
r<1500 Mpc
r<1800 Mpc
r<2100 Mpc
r<2400 Mpc
n(>M) (Mpc^-3)
M (M_sun)
10^-4
10^-6
10^-8
10^-10
10^-12
10^14
10^15
10^16
10^17


3.5
3.0
2.5
2.0
α_{BF}
600
800
1000
1200
1400
1600
1800
2000
r (Mpc)
z=0
z=0.2
z=0.35
z=0.5
z=1

Conclusions.

- The theoretical description of the halo mass function can be extended to LTB universes by adding a parameter that accounts for the effect of the background shear on the growth of perturbations.
- The value of this parameter depends mildly on t and r, with $\alpha \sim 2$. Its dependence on the void model is still under study.
- If α turned out to be cosmology-independent, halo abundances might be used to constrain the background cosmic shear.
- If applicable to $\mathcal{O}(10\,\mathrm{Mpc})$-sized voids, this treatment could be used in the modelling of environmental effects.

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THANKS FOR YOUR ATTENTION!